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Heterotic patterns among Latin America highland tropical maize cultivars

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Iowa State University, 1993



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Heterotic patterns among Latin America highland tropical maize cultivars

by

Miguel A. Barandiaran

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

> Department: Agronomy Major: Plant Breeding

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INTRODUCTION

Heterosis or hybrid vigor is defined as the superiority of the cross over the parental mean or over the parent with the highest expression of the trait (Robinson and Moll, 1965). Although the genetic basis of heterosis is still to be determined, the phenomenon of hybrid vigor has been extensively used for the improvement of yield in maize (Zea <u>mays</u> L.) and other crops. Yield heterosis in crosses of maize cultivars has been widely reported in areas where maize is grown (Hallauer and Miranda, 1988).

Variety-cross diallels provide information on heterosis and heterotic patterns which can be used in forming more than one base population. Such populations can be used as parents in the first generation crosses for grain production, or can be improved under conventional intraand inter-population selection schemes, and be a source for new promising varieties and superior lines for the production of hybrids (Comstock et al., 1949; Pandey and Gardner, 1992).

Extensive work in maize has been done in the Latin America tropical lowland areas where most of the maize growing areas are localized. Heterosis among lowland maize cultivars has been widely investigated and important heterotic patterns have been identified (Hallauer et al.,

1988). In the highlands of Latin America, however, the investigations have been limited. Very little is known about the nature of the genetic variability existing among the different races and local cultivars growing at altitudes up to 3800 m above sea level (masl).

The highland maize in Latin America is characterized by the predominantly floury endosperm-type grain and for the semi-soft endosperm type morocho. These types of maize are particularly suitable for direct human consumption. Another characteristic of this maize is the large grain yield potential. Experimental yields over 10000 kg/ha have been obtained at 3100 masl in the inter-Andean valleys in central Peru.

The objectives of the present study were to evaluate the existence of heterosis and to determine possible heterotic patterns among ten cultivars of tropical highland maize representing contrasting arrays of morphological and agronomic characteristics.

LITERATURE REVIEW

Heterosis

The term heterosis was proposed by Shull (1914) as a word to describe the phenomenon of hybrid vigor resulting from the union of different gametes. Shull's definition of heterosis implied that more than gene action was responsible for its expression; i.e., heterosis was not only Mendelian in origin, but that some interactions between the male nucleus and the egg cytoplasm were involved (Whaley, 1944). Sedcole (1981) defined heterosis either as the increased vigor of the F_1 over the mean of the parents or as the increased vigor of the F_1 over the best parent. Several hypotheses have been proposed as an explanation of heterosis. Some of the hypotheses were on a genetic basis, whereas others were not. Despite the extensive research conducted to determine the genetic basis of heterosis it has been difficult to prove or disprove the different theories (Hallauer and Miranda, 1988).

Most theories advanced to explain heterosis are included in either one of the following categories (Sprague, 1946; Brieger, 1950; Jinks, 1955; Hallauer and Miranda, 1988):

physiological stimulation resulting from the union of unlike gametes (the overdominance hypotheses), and

complementary action of dominant favorable genes of both parents, (or the dominance hypotheses).

The first theory was presented by Shull (1908) under the assumption that heterozygosity itself accounts for heterosis. East and Hayes (1912) supported this view indicating that the stimulus was greater when the characters were in heterozygous condition, and the stimulus was cumulative, depending on the number of heterozygous factors in the organism. This theory was expanded by East (1936) who postulated that different alleles when combined in heterozygotes exerted a complementary action, resulting in an increment of vigor expressed in those heterozygotes. The theory of heterozygosity as the cause of heterosis is essentially non-Mendelian.

Hull (1945) presented a Mendelian explanation of heterosis stating that if a heterozygous value exceeds that of either parent the corresponding locus should be important as a source of hybrid vigor. This is the overdominance hypotheses. Under this view, hybrid vigor itself is the cause of superiority, which would imply the physiological stimulation hypotheses or the obligatory interaction of alleles (Brieger, 1950; Sprague, 1953).

The dominance hypotheses, as a Mendelian explanation of heterosis, was first proposed mathematically by Bruce (1910), based on the lower number of recessive elements in

the hybrid as compared with those of the parents considered as one. Hallauer and Miranda (1988) pointed out that the main features of Bruce's explanation is that heterosis occurs if the parents differ in gene frequency and dominance is present. Keeble and Pellew (1910), working with garden peas, suggested that the greater vigor generally exhibited by the F_1 hybrid could be due to the action of dominant growth factors in the zygote, provided by the gametes of each parent.

Detractors of the dominance hypotheses of heterosis argued that such an explanation was not acceptable because, if true, lines as vigorous as the hybrid could be obtained. This did not seem to be possible, due to the current belief at that time that lines must be weak and lacking in vigor (Sprague, 1946). Another argument against the dominance hypothesis was that the F_2 generation of the hybrid should show a skewed distribution due to the 3:1 segregation in favor of the dominant alleles. (Hallauer and Miranda, 1988).

Jones (1917) interpreted heterosis as a result of the presence of dominant linked genes. Linkage between favorable and unfavorable genes would prevent skewness and the recovery of multiple dominant individuals (Richey, 1946). Collins (1921) demonstrated that if the number of factors controlling a character was more than ten the possibility of recovering a completely homozygous dominant individual was

very remote, and also that skewness would be difficult to detect. And indeed the number of genes controlling the expression of complex traits such as vigor, health, and productivity, though unknown, must be greater than ten (Hallauer and Miranda, 1988).

The manifestation of heterosis usually depends on genetic divergence of the parental populations; nevertheless, this concept seems to have its limits in the expression of maximum heterosis (Hallauer and Miranda, 1988). Richey (1922) reported the effect of differences in endosperm type for higher yields. He observed that crosses between different endosperm types (flours, flints, and dents) of maize were superior to crosses of dent varieties. On the other hand, Paterniani and Lonnquist (1963) indicated that crosses within endosperm types were as productive, on the average, as those between endosperm types: dent x dent and flour x flour yielded 4.44 and 4.20 t/ha, respectively, vs. 4.42 t/ha in dent x flour crosses.

Taking as a premise that genetic differences among varieties might arise as a result of geographical isolation, Moll et al. (1962) studied the crosses of six maize varieties, two from each of three different regions in the United States and Puerto Rico. Their results agreed with the original classification of the genetic divergence of the parental varieties, concluding that greater genetic

diversity was associated with greater heterosis in the variety cross. In a later study Moll et al. (1965), widened the range of genetic divergence, by adding two Mexican races to the ones considered in the previous study. They found that heterosis in crosses involving Mexican races, considered to have higher levels of genetic diversity, was less than that observed between varieties considered to be less genetically diverse. They concluded that heterosis increases with divergence within a restricted range of diversity but extremely divergent crosses resulted in a decrease in heterotic expression.

Variety crosses and heterotic patterns

Before the rediscovery of Mendel's laws at the beginning of the present century, maize breeders were aware that some crosses between varieties and between species resulted in an increased vigor (East and Hayes, 1912). The detrimental effects caused by selfing allogamous crops also were known, and that such loss of vigor became restored in the progeny once the strains subjected to inbreeding were outcrossed.

Darwin (1877) studied the effects of inbreeding and crossing in maize, and concluded that the vigor exhibited by the hybrid was the result of uniting gametes, different in constitution, and "that cross fertilization is generally

beneficial and self-fertilization injurious". Beal (1880) tested a series of hybrids between open pollinated varieties, suggesting the use of first generation varietal crosses as a means of increasing yield. This led to a rather extensive study of variety crosses during the early 1900's (Lonnquist and Gardner, 1961).

Richey (1922) summarized data previously reported by various investigators on 244 comparisons between first generation crosses and the parental varieties in maize. He found that 201 crosses (82.4%) yielded more than the parental average, and 136 crosses (55.7%) yielded more than the better parent.

Shull (1909) proposed the pure-line method in maize breeding. He emphasized that with this method all individual F_1 plants would have the same complexity and uniformity and should produce equal yield of grain. This pure line-method would have advantages over methods that selected the more heterozygous individuals as parents. Crosses between heterozygous parents would produce an offspring with varying degree of heterozygosis, which would result in a crop of lower average yield than that of the selected pure lines. For Shull, the problem was limited to finding the best combination of pure lines and the practical use of the pure lines in the production of seed. The high cost of producing hybrid seed made this method not feasible for

large scale planting, which on the other hand was not a problem for first generation variety crosses.

Similar methods to produce hybrid seed from variety crosses for commercial planting were outlined by Collins (1909) and by East (1909). They advocated the use of variety crosses as more feasible to obtain better yields in maize though they were greatly concerned about the growing expansion of research in studying new methods involving inbreeding in maize. East (1909) reported an increase of vigor over the parents after testing the first generation of 30 maize crosses. Yield was reported for only four crosses. Three of the crosses involved inbred parents, which on the average were superior in yield as compared with the cross of two varieties; i.e., 158 bu/acre (9.88 t/ha) vs. 124 bu/acre (7.75 t/ha).

The interest in variety crosses was markedly reduced after Jones (1918) proposed the use of double cross hybrids to eliminate seed cost as a limiting factor in the use of inbreds to produce hybrids. In the 1950s, interest was renewed due to the development of quantitative genetics and recurrent selection procedures for the improvement of breeding populations (Hallauer and Miranda, 1988). Evaluation of variety crosses is to provide knowledge on the potential of hybrid crosses and heterosis expressed in crosses. This information can be used for varieties to be

used as parents in the first generation crosses for grain production, as base populations in recurrent selection programs, as sources of inbred lines to be used in hybrid combination, or as materials for the synthesis of varieties composites (Comstock et al., 1949; Miranda and Vencovsky, 1984).

The identification of heterotic patterns (i.e., known crosses between populations having a greater expression of heterosis) has been of interest among maize breeders. In the United States the most extensively used heterotic pattern is that of Reid Yellow Dent by Lancaster Sure Crop (Sprague, 1984). The concern about the narrowness of the germplasm base in the U.S. Corn Belt has influenced researchers to explore alternatives to increase the genetic diversity by using either exotic germplasm or U.S. Corn Belt germplasm not extensively used (Eberhart, 1971; Kauffman et al., 1982).

Heterotic patterns are arbitrary and are derived by breeders based on experience, breeding, and testing (Hallauer et al., 1988). A systematic approach for identifying a heterotic pattern and a method of assigning a number of varieties showing heterotic response to such patterns was described by Kauffman et al. (1982). They studied the diallel crosses of nine open pollinated U.S. Corn Belt varieties with similar characteristics of yield as

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varieties per se, damaged plants, and harvest moisture. The varieties Midland and Leaming were selected to develop a heterotic pattern since they combined well with each other and with the variety Lancaster.

In a following study 111 U.S. Corn Belt variety accessions were crossed to Midland and Leaming (Kauffman et al. 1982). Based on the results of trials conducted in three years, 27 accessions were assigned to Midland and 48 to the Leaming group, which was the base to form a Midland type composite and a Leaming type composite, respectively.

Crossa et al. (1987) studied the heterotic effects among 13 populations of maize which included five adapted U.S. Corn Belt populations, five adapted x exotic (Mexican, Caribbean and Brazilian germplasm) populations, two composites of adapted and exotic germplasm (lines from Canada, France and Yugoslavia), and one exotic population (Tuxpeño x Antigua). The 100% U.S. Corn Belt populations had the highest yield in crosses (7.57 t/ha), showing consistently higher heterosis effects when crossed with all others but yielded poorly as parents per se (5.61 t/ha). The exotic population ranked second in mean cross yield (7.1 t/ha) and first as parent per se (7.0 t/ha).

Mungoma and Pollak (1988) studied ten U.S. Corn Belt and exotic maize populations, and reported the cross BSSS(R)C10 x Mexican Dent (Tuxpeño) having the highest yield

(8.77 t/ha), the highest mid-parent heterosis, and, consequently, the best heterotic combination among the ten populations for yield. Although those yields were not significantly higher than the check (B73 x Mo17) it was statistically superior to that of BSSS(R)C10 x Lancaster, which represents the widely used heterotic pattern Reid Yellow Dent and Lancaster Sure Crop.

Latin America researchers also had the same concerns of extensive use of a few germplasm sources. Paterniani and Lonnquist (1963) studied the yield produced by 12 races of maize from Brazil, Mexico, Paraguay, and Argentine and their respective crosses, thus representing a wide range of diversity with respect to origin. The average heterotic response of the crosses was 33% relative to the mid-parent and 14% relative to the higher yielding parent. They identified three races, Itaici (a Paulista dent), Cateto, and Carmen (of Tuxpeño origin) as promising for immediate use in maize breeding in Brazil.

Paterniani (1964) studied crosses among Brazilian, Colombian, and Mexican lines belonging to the heterotic pattern Cateto by Tuxpeño. Crosses of Colombian by Mexican lines yielded 55% more than the best available Brazilian double cross hybrid. Miranda and Vencovsky (1984) crossed nine open pollinated tropical varieties (seven short plant varieties and two high yielding varieties) in a complete

diallel and evaluated at five locations in 1973 and 1974. The highest yielding cross over years and locations was Tuxpeño Crema-I x Eto Blanco (5.52 t/ha), which also showed the highest heterosis for yield (34.4% over the mid-parent). Results of this study led them to conclude that all seven short plant varieties can be used to synthesize a new population because they all showed a homogeneous heterotic pattern in crosses among themselves.

Crossa et al. (1990) analyzed the results of crossing 25 different races of Mexican maize evaluated during 1961 to 1964 at three different elevations above sea level, identified as high (2244 m), intermediate (1800 m) and low (1300 m) altitude. At the high elevation Conico, Conico Norteño, and Chalqueño produced the higher yields (5.24, 5.27, and 5.41 t/ha., respectively). At the intermediate elevation, the best yielding races were Celaya (7.92 t/ha.) and Comiteco, Harinoso de Ocho, Maiz Dulce, Tabloncillo and Tuxpeño, whose yields ranged from 5.41 to 5.67 t/ha. At the low elevation, Harinoso de Ocho (5.67 t/ha.), Pepitilla (5.06 t/ha.), and Celaya (4.92 t/ha.) had the best yields. Maiz Dulce had higher yields in crosses with Reventador, Harinoso de Ocho, and Jala at high elevation, with Celaya race at intermediate elevation, and with the lowland race Tuxpeño. Cacahuazintle performed well in crosses only at the high altitude, yielding 7.05 t/ha in cross with Reventador

and 6.85 t/ha in cross with Harinoso de Ocho; heterosis was over 200% in both crosses.

Pandey and Gardner (1992), reported the possible heterotic combinations for 22 tropical maize populations managed by CIMMYT. To determine this, diallel trials starting in 1985 were set up based on adaptation, maturity, grain color, and protein quality. Evaluations were conducted at several locations in Mexico, Central and South America, the United States, and Asia.

The diallel analysis

The theory of diallel crosses and models to analyze them have been proposed and extensively discussed by several scientists (Hayman, 1954a and 1954b; Kempthorne, 1956; Jones, 1965). Originally designed to estimate genetic parameters from means of different generational populations originated from pairs of homozygous lines, the diallel analysis has been widely used by quantitative geneticists to determine the nature of gene action involved in the expression of quantitative traits, and by plant breeders interested in selecting the most promising germplasm for their programs (Gardner and Eberhart, 1966).

In interpreting genetically the results of diallel analysis, the following assumptions need to be considered (Kempthorne, 1956):

normal Mendelian diploid segregation,

no maternal effects,

no epistasis,

an arbitrary number of alleles at each locus, no environmental correlation with genotypes, and independent distribution of genes between the parents.

The last assumptions of independent distribution of genes between the parents, and no epistasis, were regarded by Baker (1978) as critical for proper interpretation of the diallel analysis. Neither assumption seems valid in a diallel mating scheme involving a relatively small number of parents. Independent distribution of genes at n loci cannot occur unless a minimum of 2^n parents are included in the diallel crosses. For maize, estimates of epistasis seem to be negligible relative to additive and dominance effects (Hallauer and Miranda, 1988). Failure of these assumptions could result in biased estimates of general and specific combining ability components of variance, and an overestimation of the average level of dominance (Baker, 1978).

The interpretation of the results obtained from a diallel analysis is restricted to the statistical model used, whether the parents are considered either as a random sample representing the reference population (random model), or as a fixed sample where conclusions are to be made solely

relative to the parents included in the sample (fixed model). In the random model case estimates of genetic component of variance can be calculated to determine the relative importance of additive and dominance action of the genes controlling the expression of the character of interest in the reference population. In the second situation, estimates of the relative importance of general and specific combining ability effects are possible (Hallauer and Miranda, 1988). It also seems reasonable to consider a random sample of genotypes as fixed if interest is also directed towards the determination of genetic effects proper for that sample (Baker, 1978).

The choice of either model, and whether or not parents and reciprocals are included in the analysis, gives rise to eight different situations involving different estimation procedures and different tests of hypotheses. Griffing (1956) examined in detail each analysis grouping them in what he named as methods 1, 2, 3, and 4 for random and fixed models.

In maize, early breeding programs were mostly interested in evaluating the combined ability of inbred lines by means of topcross and single cross tests. This unique concept of combining ability was refined by Sprague and Tatum (1942), when they first proposed its partition into general and specific combining ability (Hallauer and

Miranda, 1988).

The term 'general combining ability' (GCA) is used to indicate 'the average performance of a line in hybrid combination' when expressed as a deviation from the mean of all crosses including that line. 'Specific combining ability' (SCA) refers to the performance of single combinations on the basis of the average performance of the lines involved in that cross.

Lower estimates of GCA indicate that the line is performing similar to the average of all lines in crosses. Larger estimates of GCA for a line can arise because it is either better or poorer than the rest of the lines in the study. This is interpreted as caused by the presence of genes that are mostly additive in their effects (Sprague and Tatum, 1942).

Similarly, lower estimates of SCA are taken as an indication of an expected performance of a particular combination on the basis of the GCA of its parents. Higher values of SCA indicate that some crosses were better or poorer than expected, also based on the GCA of its component parents. Thus, specific combining ability is greatly dependent on genes with dominance or epistatic effects (Sprague and Tatum, 1942). With the increasing interest in variety crosses in the 1950s, methods of evaluation and choice of varieties for heterosis also changed from crossing

a group of varieties to a common tester variety, to the use of the diallel mating design to determine the general and specific combining ability of varieties and their crosses (Hallauer and Miranda, 1988).

Methods for evaluating diallel crosses for a fixed set of parents and one set of F_1 crosses were proposed by Griffing (1956), and by Gardner and Eberhart (1966). Griffing's method 2, model 1, allows the partition of entries sum of squares in general and specific combining ability but does not provide a measurement for heterosis effects as does Gardner and Eberhart's analysis II and III. On the other hand, analysis III separates the effects of both varieties and their crosses on the genetic basis that the difference in yield between the parental inbred lines of maize and their crosses is considerable, and, therefore, two linear models are considered (Gardner and Eberhart, 1966). In this respect analysis III is similar to that of Sprague and Tatum (1942), and Griffing's method 4, which also can be applied to variety crosses (Lonnquist and Gardner, 1961).

Analysis II of Gardner and Eberhart (1966) is of particular interest for maize variety crosses. It maximizes the information on variety performance and the expression of heterosis of their crosses (Hallauer and Miranda, 1988). The analysis gives a single model for varieties and their F_1 crosses. It also estimates heterosis effects independently

which are further subdivided in its components as defined by Hayman (1954a), who suggested that heterosis is attributable to an average heterosis (h), to an average contribution of each variety in its crosses (h_i and h_j), and to a specific effect after crossing varieties *i* and *j* (s_{ij}). By testing a series of sequential models it is possible to determine the importance of heterosis and its components:

Model 1: $Y_{ij} = \mu_v + \frac{1}{2}(v_i + v_j);$ Model 2: $Y_{ij} = \mu_v + \frac{1}{2}(v_i + v_j) + \tau h;$ Model 3: $Y_{ij} = \mu_v + \frac{1}{2}(v_i + v_j) + \tau h + (h_i + h_j);$ and Model 4: $Y_{ij} = \mu_v + \frac{1}{2}(v_i + v_j) + \tau h + (h_i + h_j) + \tau s_{ij}.$

Model 1 assumes no heterosis. Model 2 assumes that heterosis is present and it is, on the average, the same for all variety crosses. Model 3 assumes that each variety has its own unique heterotic effects in all its crosses. Model 4 assumes in addition, that each cross has its own specific heterotic effects (Gardner, 1965).

MATERIALS AND METHODS

Ten varieties of highland maize from Colombia, Ecuador, Mexico, and Peru were considered in this study. A brief description of each variety is provided.

Cacahuazintle is classified as a pre-Columbian exotic Mexican race, adapted to elevations between 2200 to 2800 meters above sea level (m.a.s.l.). Plants are of medium height and medium maturity. Kernels have white and floury endosperm (Wellhausen et al., 1952).

Chalqueño is considered a modern incipient Mexican race, adapted to altitudes from 1800 to 2300 m.a.s.l. Plants have medium to tall height and medium maturity. Kernels have soft, white endosperm. This cultivar is thought to be product of the hybridization of Conico and Tuxpeño (Wellhausen et al., 1952).

Conico 7 is an improved version of a pre-historic mestizo Mexican race grown at altitudes between 2200 to 2800 m.a.s.l. Plants are of medium size in height and very early in maturity. Kernels have hard white endosperm. Its origin is attributed to a hybridization of Palomero and Cacahuazintle (Wellhausen et al., 1952).

Cabuya is classified as a hybrid race adapted to elevations between 2100 and 2645 m.a.s.l. in Colombia. Plants are medium to tall in size and medium to late

maturity. Kernels are white or yellow and have either floury or flinty endosperm. It is a hybrid of Sabanero and Clavo (Roberts et al., 1957).

Cacao is also a Colombian hybrid race adapted to medium elevations (1300 to 1700 m.a.s.l.). Plants are medium to tall in size and early maturity. Kernels have white or yellow endosperm. It is believed to be a hybrid of Costeño and Sabanero (Roberts et al., 1957).

INIAP 153 is an Ecuatorian cultivar adapted to altitudes between 2200 to 2600 m.a.s.l. Plants are medium to tall in height and are medium to late maturity. Kernels are floury-flinty and white in color. This cultivar is derived from collections of the Zhima ecotype, belonging to the race Cuzco Ecuatoriano (Galarza, 1981).

Morocho Ecuatoriano is a cultivar that includes a large number of collections adapted to altitudes from 1700 to 3000 m.a.s.l. bearing the name Morocho. Plants are medium to tall in height. Kernels are white with flint-type endosperm. Morocho is considered as an intermediate member within a series running from Montaña Ecuatoriano to Palillo Ecuatoriano (Timothy et al., 1963).

Blanco Urubamba is a cultivar from the Peruvian race Cuzco Gigante, grown at average altitudes of 2800 m.a.s.l. Plants are medium to tall in height and are late in maturity. Kernels are floury with white endosperm. Its

origin is not clear; presumably it is a hybrid race of an 8-rowed Cuzco and Pardo, a low altitude 8-rowed floury race (Grobman et al., 1961).

Umutu is a cultivar that is grown at elevations of 2200 to 2900 m.a.s.l. in localized areas of northern Peru. Plants are medium to tall in height and are late in maturity. Kernels have white endosperm and yellow pericarp.

Morocho Ayacuchano is a cultivar from the race Morocho grown in the low altitude valleys of south-central Peru. Plants are short in height and early in maturity. The endosperm is yellow with a flinty texture. Morocho seems to be a hybrid of Proto-Confite Morocho and Confite Chavinense (Grobman et al., 1961).

The ten cultivars were crossed in a diallel scheme at Cajamarca, Peru, during the 1990-1991 planting season. Eight paired rows of 22 plants per row were used. Bulked pollen was used to pollinate as many possible plants of the opposite row and vice versa. Difficulties in matching silk emergence and pollen shed required in some cases storage of pollen at cold temperatures to be used later for making crosses. At harvest ears were hand harvested and bulked for each cross. Enough seed for making crosses and for evaluation per se was obtained from the International Maize and Wheat Improvement Center (CIMMYT) for the Mexican cultivars and from the corresponding National Maize Programs

for the Colombian, Ecuatorian, and Peruvian cultivars.

During the planting season of 1991-1992, the ten cultivars, one set of their 45 F_1 crosses, and a local check were evaluated in a 7 x 8 rectangular lattice with two replications at seven locations in three (Bolivia, Ecuador, and Peru) Andean countries. The following locations were used:

Baños del Inca (Cajamarca, Peru): 2754 m.a.s.l.
Pampa Grande (Cajabamba, Peru): 2650 m.a.s.l.
Anta (Huaraz, Peru): 2650 m.a.s.l.
Jangas (Huaraz, Peru): 2700 m.a.s.l.
Santa Catalina (Quito, Ecuador): 2950 m.a.s.l.
Chuquipata (Cuenca, Ecuador): 2400 m.a.s.l.
Pairumani (Cochabamba, Bolivia): 2580 m.a.s.l.

The experimental unit was a two-row plot with each row consisting of 11 hills. The distance between rows was 0.80 m and between hills was 0.50 m. The experiments were hand planted with three seeds per hill and later thinned to two seedlings per hill to give a stand equivalent to 50000 plants per hectare. Each entry was assigned to its respective experimental unit at each location according to its own randomization plan.

The agronomic management was that recommended for each experimental site. Chemicals were used to keep the fields free of insects and weeds. Chemical fertilizers were also

applied at the recommended rates for maize production.

Data were collected in all experiments for days to 50% female flowering, plant and ear height (cm) [the average of ten plants measured from soil surface to the ligule of the flag leaf (plant height) and the node bearing the uppermost ear (ear height)], root and stalk lodging (as percentage of the total harvested plants), grain moisture content (as percentage of its weight at harvest time), total grain yield (as t/ha adjusted to 15.0% of grain moisture).

Ten ears were taken at random from each plot, and the following data were recorded for each ear: ear length (cm), ear diameter (cm), cob diameter (cm), row number, kernel number per row, and the weight (g) of 300 kernels taken at random after having reached moisture equilibrium with the environment. Ear volume (cm³) was calculated as [(ear diameter/2)² (ear length) (π)]. Kernel depth (cm) was estimated as the difference of average ear diameter minus average cob diameter, divided by two. The average of ten ear measurements was used in data analyses.

Values for heterosis, expressed as percentage, were calculated as follows for mid-parent and high-parent heterosis:

Mid-parent (MP) heterosis: $[(F_1 - MP)/MP] * 100$ High-Parent (HP) heterosis: $[(F_1 - HP)/HP] * 100$

Analysis of variance for the following traits at each location was performed: grain yield, 50% female flowering, grain moisture content at harvest, plant height, ear height, root lodging, stalk lodging, ear volume, kernel depth, and number of kernels per row. Combined analysis of variance across the seven locations was conducted for all traits. Locations were considered as random effects in the analysis of variance; consequently, the pooled error mean square was used to test the significance of entry by location interaction mean square whereas entry mean square (cultivars and their crosses) was tested against entry by location interaction mean square. Gardner and Eberhart's analysis II (1966) was used to partition the total variation among entries in variety and heterosis effects. The variety effect (v_i) represents part of the additive gene effects and is the difference between the mean of each variety per se and the mean of all varieties considered in the study. The heterosis effects (h_{ij}) occur when variety i is crossed to variety j, and are related to nonadditive gene effects (Gardner, 1967).

The heterosis effects were further partitioned into average heterosis (h), which is the difference between the mean of all crosses and the mean of all parental varieties, variety heterosis (h_i) , which is the average contribution of heterosis by variety *i* in its crosses measured as a deviation from average heterosis, and specific heterosis

 (s_{ij}) , which measures the deviation of the observed performance of a specific cross from its expected performance based on variety effects, average heterosis, and variety heterosis (Crossa et al., 1987).

The linear model for Gardner and Eberhart's analysis II is the following:

 $Y_{ij} = \mu_v + \frac{1}{2}(v_i + v_j) + \tau h + \tau (h_i + h_j) + \tau s_{ij}, \text{ where }$

 Y_{ij} = the observed mean for a cross between varieties *i* and *j*; μ_v = the mean of all varieties; v_i , v_j = the variety effects for varieties *i* and *j*; h = the average heterosis effects for all crosses; h_i, h_j = the variety heterosis effects for varieties *i* and *j*; s_{ij} = the specific heterosis for a cross between varieties *i* and *j*; and τ = a conditional coefficient that equals zero when i = j,

and one when $i \neq j$.

The total variation for entry sum of aquares was also partitioned by fitting the linear models for Gardner and Eberhart's analysis III:

. . . .

 $Y_{ii} = \mu_v + v_i$, and

 $Y_{ij} = \mu_c + g_i + g_j + s_{ij}$, where

 Y_{ii} = the observed mean for the *i*th variety;

 μ_v = the mean of all varieties;

 v_i = the variety effects when parent varieties are included in the analysis;

 Y_{ij} = the observed mean for the cross between varieties *i* and *j*;

 μ_{c} = the mean of all crosses;

 g_i , g_j = the general combining ability effects for varieties *i* and *j*; and

 s_{ij} = the specific combining ability effects for that particular cross.

The outline for the diallel analysis of variance combined across locations is presented in Table 1. This is a nonorthogonal partition of variability among entries with the insertion of the variation contributed by the general combining ability effects.

The term 'cultivar' will be used instead of 'variety' to keep consistency with the germplasm used in this study.

Source	df	Expected mean squares
Total	ner ^a -1	
Locations (L)	e-1	
Replication/L	r-1	
Entries (n)	[n(n+1)/2] - 1	$\sigma^2 + r\sigma^2_{L.n} + reK^2_n$
Cultivars (C)	n-1	$\sigma^2 + r\sigma^2_{L.C} + reK^2_{c}$
GCA ^b	n-1	$\sigma^2 + r\sigma^2_{L.gca} + re(n-2)K^2_{gca}/(n-1)$
Heterosis (h)	n (n-1) /2	$\sigma^2 + r\sigma^2_{L,h} + reK^2_h$
Average (Ah)	1	$\sigma^2 + r\sigma^2_{L,Ah} + reK^2_{Ah}$
Cultivar (Ch)	n-1	$\sigma^2 + r\sigma^2_{\text{L.Ch}} + reK^2_{\text{Ch}}$
Specific (Sh)	n(n-3)/2	σ^2 + $r\sigma^2_{L.Sh}$ + $2reK^2_{Sh}/n(n-3)$

Table 1. Sources of variation and expected mean squares for combined analysis across locations in diallel cross experiments among varieties

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^a e, r and n are locations, replications and entries, respectively. ^b General combining ability.
RESULTS AND DISCUSSION

Grain yield

Analysis of variance for each location is presented in Table A1 (Appendix). There were highly significant ($P \le 0.01$) differences among entries (cultivars and their F_1 crosses) for all locations except for Jangas. The partition of entry sum of squares, according to models II and III of Gardner and Eberhart (1966), showed that cultivars and heterosis effects were also highly significant. In all locations except Santa Catalina, heterosis accounted for most of the variation. General combining ability effects also were statistically significant indicating the presence of favorable additive gene effects.

Among the components of heterosis, specific heterosis explained most of the variation though it was significant only at four locations (Anta, Santa Catalina, Chuquipata, and Pairumani). Average heterosis was highly significant for all locations indicating that the mean of the cultivar crosses was greater than the mean of cultivars per se (Table A1).

The combined analysis of variance across the seven locations (Table 2) shows highly significant differences for all main sources of variation and first order interactions except for location x cultivar heterosis (L x Ch).

		Mean square
Source	di	Grain yield
Location (L)	6	657.75**
Replication /L	7	10.03**
Entry	54	17.79**
Cultivar (C)	9	26.44**
GCA ^a	9	23.62**
Heterosis (h)	45	16.06**
Average (Ah)	1	345.47**
Cultivar (Ch)	9	9.05**
Specific (Sh)	35	8.45**
L x entries	324	3.05**
LxC	54	7.80**
L X GCA	54	5.31**
L x h	270	2.09*
L x Ah	6	6.48**
L x Ch	54	1.70
L x Sh	210	2.07*
Pooled error	378	1.63
C.V.(%) S.D. Mean		21.08 1.28 6.06

Table 2. Combined analysis of variance across locations for grain yield (t/ha) for ten maize cultivars and their 45 diallel crosses

^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

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Most of the total variability was for differences among locations (60%). The locations represent a wide range of environments from 2400 to 2950 meters above sea level, which is characteristic of maize growing areas in the high elevations of the Andean region. The location x entry interaction was also highly significant, indicating different performances of the cultivars at each location.

Cultivar and heterosis effects were highly significant as it also was general combining ability effects (Table 2). This is an indication of the existence of favorable gene effects for yield among cultivars. However, it seems that nonadditive gene effects were important in the expression of yield among the cultivars is this study. Heterosis effects accounted for 75% of the total variability for entries, and specific heterosis accounted for 41% of the total heterosis sum of squares. The importance of these sources of variation was also reported by several authors working with open pollinated maize germplasm.

Genter and Eberhart (1974) studied 13 U.S. Corn Belt populations included in diallel crosses, and they reported heterosis effects as more important than cultivar effects for yield. Mungoma and Pollak (1988) found a higher contribution of heterosis effects than cultivar effects to the total variation among entries for ten populations representing U.S. Corn Belt material and lowland exotic

germplasm. Crossa et al. (1990), however, in a study involving 25 highland races of Mexican maize at three different elevations found that the presence of additive effects was more important than nonadditive gene effects. Similar trends were also reported by Miranda and Vencovsky (1980) working with nine open pollinated varieties of tropical lowland maize.

All components of heterosis were highly significant. Average heterosis was the most important component. The yield of all ten cultivars in crosses was higher than their yields per se; the average yield of cultivars in crosses was 37.3% greater than the average yield of the parental cultivars per se (6.37 t/ha versus 4.64 t/ha) (Table 3). Genter and Eberhart (1974) reported a 15% superiority of crosses over their parents. Specific heterosis (s_{ij}) was also a significant component of heterosis indicating that there were important differences among crosses (Table 2). The partition of the sum of squares of crosses following the analysis III of Gardner and Eberhart (1966) showed that the contribution of specific combining ability effects (58%) was higher than that of general combining ability effects (42%).

The cultivars INIAP 153, Blanco Urubamba, and Umutu had the highest yield per se with 5.76, 5.76, and 5.67 t/ha, respectively (Table 3). These yields were reflected in the highest and highly significant values for cultivar effects

(1.12, 1.12, and 1.03 t/ha), suggesting the presence of a higher frequency of favorable alleles as compared with the other cultivars. On the other hand, these cultivars had negative values for cultivar heterosis effects (h_i) which might be explained because their yields per se were better than their yields in crosses with respect to the rest of cultivars. Cultivar heterosis must be considered cautiously because its value is a function of both the difference between the mean of a parental cultivar *i* in crosses and the

Table 3. Average grain yield (t/ha) for ten cultivar of maize per se and in crosses and estimates of GCA^a effects (g_i), cultivar effects (v_i), and cultivar heterosis effects (h_i)

		Y	ield	· · · · · · · · · · · · · · · · · · ·		
(Cultivar j	<u>oer se</u>	crosses	g	v_i	<u> </u>
1.	Cacahuaz.	3.79	6.30	-0.08*	-0.85**	0.34**
2.	Chalqueño	4.94	6.49	0.14**	0.30**	-0.01
3.	Conico 7	4.03	6.34	-0.04	-0.61**	0.26**
4.	INIAP 153	5.76	6.71	0.38**	1.12**	-0.18
5.	Mor. Ecuat.	4.18	5.95	-0.47**	-0.45**	-0.25*
6.	Cacao	3.22	6.68	0.35**	-1.42**	1.06**
7.	Cabuya	5.07	6.65	0.31**	0.43**	0.09
8.	Blanco Urub	5.76	6.45	0.08*	1.12**	-0.48**
9.	Umutu	5.67	6.72	0.39**	1.03**	-0.12
10.	Mor. Ayac.	3.97	5.43	-1.06**	-0.67**	-0.72**
Ì	lean	4.64	6.37			

LSD_(0.05) for cultivars per se: 0.95 t/ha. LSD_(0.05) for cultivars in crosses: 0.32 t/ha. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

mean of all crosses, and of the difference between its mean per se and average per se mean of all other cultivars (Crossa et al., 1990).

The Colombian cultivar Cacao had the lowest yield per se (3.22 t/ha), but showed highly significant GCA effects (0.35) and the largest positive value for cultivar heterosis effects (1.06). This result suggests that Cacao has a frequency of favorable dominant alleles different from the other cultivars and has good general combining ability. Cacahuazintle and Conico 7 also had low yields per se (3.79 and 4.03 t/ha), good yield in crosses, and a positive value for cultivar heterosis effects (0.34 and 0.26) (Table 3).

The cross Cacahuazintle x Cacao was the highest yielding combination (8.01 t/ha) and also showed the highest specific combining ability (SCA) effects (1.36) (Table 4). This cross also had the highest values for both mid-parent (MP) heterosis (128.8%) and high-parent (HP) heterosis (111.2%) (Table A2).

Negative values for SCA were obtained in crosses of INIAP 153 and Morocho Ecuatoriano from Ecuador with the Colombian cultivars Cacao and Cabuya and with Blanco Urubamba from Peru (Table 4). The same trend occurred in crosses involving Cacao and Cabuya with Blanco Urubamba and Umutu. Despite this, these crosses, except Morocho Ecuatoriano x Blanco Urubamba (-4.1%), presented positive HP

Table 4. Average grain yield (t/ha) over seven locations (above diagonal) and specific combining ability effects (below diagonal) for 45 F_1 crosses among ten maize cultivars

	ultivars	1	_2	3	4	5	6	7	8	9	10
1.	Cacahuaz.		5.13	5.24	6.80	6.29	8.01	6.81	6.41	6.67	5.39
2.	Chalqueño	-1.30**		4.95	6.96	6.56	7.15	7.39	7.18	7.86	5.23
3.	Conico 7	-1.02**	-1.48**		7.74	6.38	7.53	7.17	7.25	6.45	4.32
4.	INIAP 153	0.12*	0.06	1.02**		5.13	6.60	6.71	6.32	7.55	6.63
5.	Morocho Ec.	0.46**	0.52**	0.51**	-1.16**		5.99	5.98	5.52	6.91	4.83
6.	Cacao	1.36**	0.29**	0.84**	-0.50**	-0.26**		5.70	6.23	6.38	6.57
7.	Cabuya	0.21**	0.57**	0.52**	-0.36**	-0.23**	-1.33**		7.37	7.04	5.68
8.	Blanco Urub.	0.03	0.59**	0.83**	-0.52**	-0.46**	-0.57**	0.60**	r	6.57	5.18
9.	Umutu	-0.02	0.96**	-0.28**	0.40**	0.62**	-0.73**	-0.03	-0.27**		5.07
10.	Morocho Ay.	0.15**	-0.22**	-0.96**	0.93**	-0.01	0.91**	0.05	-0.22**	-0.64**	

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LSD_(0.05) for crosses: 0.95 t/ha. *,** Significant at 0.05 and 0.01 probability levels, respectively.

heterosis values (Table 2). On the other hand, the Mexican cultivars Cacahuazintle, Chalqueño, and Conico 7 had positive SCA with INIAP 153, Morocho Ecuatoriano, Cacao, Cabuya, and Blanco Urubamba (Table 4). Crosses between cultivars from the same country had negative SCA effects, and their yields were lower among of all crosses.

All values for MP heterosis were positive, indicating a favorable frequency of dominant alleles for yield among the cultivars. Higher heterosis values were obtained from crosses between cultivars from different countries rather than from crosses between cultivars belonging to the same country. This relation seems reasonable because cultivars from the same geographical region are more likely to share common ancestors and, therefore, are expected to be less genetically diverse.

Female flowering and grain moisture content

The analyses of variance for female flowering and grain moisture content for each location are presented in Tables A3 and A5 in the appendix. Table 5 includes the combined analysis of variance across locations. There were significant differences among all main sources of variation for female flowering and grain moisture content.

For days to 50% female flowering, differences among entries accounted for 67% of the total variation for this

		Mean squares					
Source	df	Female flowering	Moisture content				
Location (L)	6	3978.2**	5795.21**				
Replication /L	7	21.8	29.90*				
Entry	54	1611.3**	239.20**				
Cultivars (C)	9	9164.1**	1317.94**				
GCA ^a	9	5690.7**	870.34**				
Heterosis (h)	45	100.7**	23.45				
Average (Ah)	1	967.1**	206.33**				
Cultivar (Ch)	9	106.8**	9.96				
Specific (Sh)	35	74.4**	21.70				
L x entries	324	31.6*	43.21**				
ГХС	54	62.8**	156.70**				
L X GCA	54	40.7**	109.42**				
Lxh	270	25.4	20.51**				
L x Ah	6	43.3	24.28				
L x Ch	54	16.1	26.66**				
L x Sh	210	27.2	18.82**				
Pooled error	378	23.9	11.72				
C.V.(%)	<u> </u>	5.1	11.76				
Mean		96.6	29.11				

Table 5. Combined analysis of variance across locations for female flowering (days) and moisture content (%) for ten maize cultivars and their 45 diallel crosses

^a General combining ability.
*,** Significant at 0.05 and 0.01 probability levels, respectively.

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trait, whereas for grain moisture content locations, that accounted for 52% of the total variation, was the most important source of variation.

Cultivar effects were more important than heterosis effects accounting for 95% for female flowering and 91% for grain moisture content of the total variability for entries. General combining ability (GCA) effects were highly significant for both traits, suggesting the importance of alleles with additive effects. Nonadditive gene effects seemed of minor importance for grain moisture content.

Heterosis and all its components were highly significant for female flowering. Cultivar and specific heterosis effects were not statistically significant for grain moisture content, but average heterosis was highly significant (Table 5) indicating the presence of heterosis for this trait. The locations x entries interactions were highly significant for both traits. For female flowering, the location by heterosis interactions and all its components were not significant, indicating the relative consistency of heterosis effects across locations for female flowering. For grain moisture content, location x average heterosis interaction was not significant.

Days to female flowering and grain moisture content at harvest time are characteristics related to maturity. They provide an indication of the relative earliness or lateness

Table 6. Average female flowering (days) for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) , and cultivar heterosis effects (h_i)

		Female	flower	ring		
	<u>Cultivar</u>	<u>per s</u>	e cross	ses g _i	v_i	<u> </u>
1.	Cacahuazintl	e 85	89	-7.94**	-14.1**	-0.9*
2.	Chalqueño	84	91	-5.38**	-14.6**	1.9**
з.	Conico 7	83	89	-7.96**	-16.3**	0.2
4.	INIAP 153	108	101	6.09**	8.7**	1.7**
5.	Mor. Ecuat.	121	104	9.05**	22.1**	-2.0**
6.	Cacao	119	104	8.87**	20.4**	-1.3**
7.	Cabuya	108	100	4.86**	8.9**	0.4
8.	Blanco Urub.	102	97	1.32**	3.5**	-0.4
9.	Umutu	103	96	-0.04	4.4**	-2.2**
10.	Mor. Ayac.	76	88	-8.87**	-23.1**	2.7**
	Mean	99	96	······································		

LSD_(0.05) for cultivars per se: 3.63 days. LSD_(0.05) for cultivars in crosses: 1.21 days. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

of a cultivar compared with others.

The three Mexican cultivars (i.e., Cacahuazintle, Chalqueño, and Conico 7), and Morocho Ayacuchano flowered 20 days earlier than the other cultivars. Morocho Ayacuchano was the earliest cultivar with 76 days after planting. A second group with days to female flowering, ranging from 102 to 108 days, was represented by INIAP 153, Cabuya, Blanco Urubamba, and Umutu. The remaining two cultivars, Morocho Ecuatoriano and Cacao, were the latest flowering, 121 and 119 days after planting, respectively (Table 6).

Cultivar effects (v_i) were highly significant for all cultivars (Table 6). General combining ability (GCA) effects effects also were significant for all cultivars but Umutu. Negative values for GCA effects and cultivar effects are desirable when earlier flowering is desired. The four cultivars that had negative and significant values for both GCA and cultivars effects were those identified as the earliest flowering (Table 6). This suggests the presence of a higher frequency of favorable alleles for earlier flowering among these cultivars. In general, there was a good agreement between the cultivar means per se and their respective values for variety effects (Table 6).

Among crosses, the range for female flowering was from 77 (Conico 7 x Morocho Ayacuchano) to 118 days (INIAP 153 x Morocho Ecuatoriano), (Table 7). Crosses between INIAP 153 with Conico 7 and Morocho Ecuatoriano had the lowest (-4.4) and the highest values (6.3) for specific combining ability (SCA) effects. Conico 7 x Morocho Ayacuchano was the only cross among the earlier flowering cultivars with negative SCA effects (-2.5). Among the later flowering cultivars, crosses of INIAP 153 with Umutu and Cacao had negative and highly significant values for SCA effects (-3.6 and -3.2, respectively).

Negative values for mid-parent (MP) heterosis indicate

Table	7.	Average female flowering (days) over seven locations (above diagonal)	
		and specific combining ability effects (below diagonal) for 45 F_1 crosses	5
		among ten maize cultivars	

C	ultivars	1	2	3	4	5	6	7	8	9	10
1.	Cacahuazintle		84	83	94	97	97	92	88	86	79
2.	Chalqueño	1.6**		83	97	102	100	96	90	91	80
3.	Conico 7	2.4**	0.2		90	95	100	94	90	90	77
4.	INIAP 153	-0.3	0.6**	-4.4**		118	108	107	106	98	95
5.	Morocho Ecuador	0.2	1.9**	-2.2**	6.3*	*	113	110	104	105	94
6.	Cacao	-0.1	0.1	3.5**	-3.2*	*-1.2**	•	109	105	105	99
7.	Cabuya	-0.9**	0.2	0.7**	0.2	0.3	-1.1**		103	101	92
8.	Blanco Urubamba	-1.1**	-2.3**	0.7**	2.8*	*-2.1**	-1.6**	1.0**	•	99	90
9.	Umutu	-1.8**	-0.1	2.0**	-3.6*	*-0.3	0.4*	0.2	1.3**		89
10.	Morocho Ayacucho	0.1	-2.3**	-2.5**	1.7	* -2.6**	3.0**	-0.5**	1.2**	1.8**	

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LSD_(0.05) for crosses: 3.6 days. *,** Significant at 0.05 and 0.01 probability levels, respectively.

that the performance of the F_1 crosses is towards the earliest flowering parent. Most values (87%) of MP heterosis among crosses and all values of high-parent (HP) heterosis were negative (Table A4). Also, the lowest values for heterosis were obtained from crosses between earlier and later flowering cultivars.

For grain moisture content the results followed the same trend as was described for female flowering. The ten cultivars can be included in two distinct groups for low and high moisture content. The cultivars with the lowest grain moisture at harvest were Cacahuazintle (22.9%), Chalqueño (25.1%), Conico 7 (21.8%), and Morocho Ayacuchano (27.0%). (Table 8). These four cultivars also had highly significant negative estimates for both general combining ability (GCA) and cultivar effects, suggesting the existence of favorable alleles for lower grain moisture content. The other six cultivars with the highest grain moisture content had positive and highly significant values for GCA effects and cultivar effects. The largest positive values for cultivar heterosis (h_i) were for INIAP 153 (0.86) and Cacahuazintle (0.60), whereas the largest negative value was for Morocho Ecuatoriano (-0.91) (Table 8).

Within the group of cultivars with lower moisture content, the cross between Conico 7 x Morocho Ayacuchano had the lowest negative value (-0.68) for specific combining

Table 8. Average grain moisture content (%) for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) , and cultivar heterosis effects (h_i)

	1	loisture	e conten	t		
	<u>Cultivar</u>	<u>per se</u>	crosses		v_i	<u> </u>
1.	Cacahuazintle	22.9	26.2	-3.02**	-7.25**	0.60*
2.	Chalqueño	25.1	26.7	-2.42**	-5.10**	0.13
з.	Conico 7	21.8	24.7	-4.63**	-8.43**	-0.42
4.	INIAP 153	35.4	31.9	3.46**	5.20**	0.86**
5.	Mor. Ecuat.	37.2	31.1	2.57**	6.96**	-0.91**
6.	Cacao	31.9	29.4	0.65**	1.71**	-0.20
7.	Cabuya	31.6	29.3	0.54**	1.42**	-0.17
8.	Blanco Urub.	37.3	31.8	3.27**	7.14**	-0.30
9.	Umutu	31.8	29.8	1.10**	1.58**	0.31
10.	Mor. Ayac.	27.0	27.5	-1.51**	-3.24**	0.11
	Mean	30.2	28.8			

LSD_(0.05) for cultivars per se: 2.54%. LSD_(0.05) for cultivars in crosses: 0.85%. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

ability (SCA) effects (Table 9). The cross between the two Colombian cultivars (Cacao x Cabuya) had -1.23 in the high moisture content group. Chalqueño x Morocho Ayacuchano had the highest positive SCA value with 2.53.

Negative HP heterosis ranged from -2.5% (Morocho Ecuatoriano x Cacao) to -33.7% (Conico 7 x Morocho Ecuatoriano). Values for mid-parent heterosis were mostly negative indicating the tendency of expression for this trait towards lower moisture content (Table A6).

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Table 9. Average grain moisture content (%) over seven locations (above diagonal) and specific combining ability effects (below diagonal) for 45 F₁ crosses among ten maize cultivars

<u> </u>	ultivars	_1	2	3	4	5	6	7	8	9	<u> 10 </u>
1.	Cacahuazintle		23.7	21.6	27.4	28.6	27.5	27.6	28.5	26.0	24.6
2.	Chalqueño	0.24		21.6	27.8	29.6	26.9	27.5	28.4	27.8	27.5
3.	Conico 7	0.39**	-0.16		26.7	24.6	25.5	27.0	28.7	24.8	22.0
4.	INIAP 153	-1.86**	-2.41	**-0.94**		36.2	32.3	33.6	36.3	34.3	33.0
5.	Morocho Ecuador	0.20	0.59'	*-2.15**	1.33**	-	32.5	31.4	34.8	33.6	29.0
6.	Cacao	1.05*'	-0.23	0.60**	-0.63**	0.37**		28.8	33.1	30.7	27.7
7.	Cabuya	1.24**	0.52	** 2.27**	0.71**	-0.55**	-1.23**	;	32.1	29.7	26.3
8.	Blanco Urubamba	-0.64**	-1.31	** 1.23**	0.66**	0.07	0.34*	-0.59**	r	34.1	29.9
9.	Umutu	-0.93**	0.24	-0.57**	0.90**	1.04**	0.05	-0.77**	0.91**	:	27.6
10.	Morocho Ayacuch	00.30	2.53	**-0.68**	2.23**	-0.91**	0.32*	-1.61**	-0.67**	-0.86	**

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LSD_(0.05) for crosses: 2.54%. *,** Significant at 0.05 and 0.01 probability levels, respectively.

Plant height and ear height

The analysis of variance for plant and ear height per location are presented in Tables A7 and A9. On the average, plants were taller at Pairumani (292.4 cm) and shorter at Pampa (161.3 cm) (Table A7). The unfavorable growing season at Pampa, characterized by the absence of rainfall, caused a significant reduction in plant size at this location.

In the combined analysis of variance across locations differences among locations accounted for 63% of the total variation for plant height and 45% for ear height (Table 10). Differences among entries also were highly significant and the highly significant interaction locations x entries indicates a differential response of the cultivars to the distinct environments for both plant and ear size.

Most of the total variation among entries for plant (87%) and ear (90%) height was caused by cultivar effects. Miranda and Vencovsky (1984) also reported that 87% of the total sum of squares for entries was due to cultivar effects for a diallel study that included nine lowland open pollinated maize varieties. General combining ability (GCA) effects were highly significant, and their contribution (88%) to the total variation among crosses (Gardner and Eberhart's analysis III) was greater than specific combining ability (SCA) effects (12%) indicating that additive effects

		Mean squares				
Source	df	Plant height	Ear height			
Location (L)	6	184076.1**	77246.9**			
Replication /L	7	2921.2**	1856.9**			
Entry	54	4743.3**	4286.6**			
Cultivars (C)	9	24856.2**	23038.8**			
GCA ^a	9	16398.5**	14712.8**			
Heterosis (h)	45	720.8*	536.1			
Average (Ah)	1	8027.4**	2727.3**			
Cultivar (Ch)	9	558.8	451.9			
Specific (Sh)	35	553.6	495.1			
L x entries	324	626.6*	552.9**			
LXC	54	1770.9**	1699.3**			
L X GCA	54	1487.8**	1442.7**			
Lxh	270	397.7	323.6			
L x Ah	6	457.3	172.9			
L x Ch	54	530.4	550.9*			
L x Sh	210	361.9	269.5			
Pooled error	378	432.9	384.3			
C.V.(%) S.D. Mean	<u> </u>	9.4 20.8 221.9	15.3 19.6 128.5			

Table 10. Combined analysis of variance across locations for plant height (cm) and ear height (cm) for ten maize cultivars and their 45 diallel crosses

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^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

were more important in the expression of plant and ear height. Vasal et al. (1993a) reported that both GCA and SCA were highly significant for plant height in a diallel involving nine CIMMYT quality protein lowland maize populations. In a following study, Vasal et al. (1993b) found GCA to be highly significant for ear height among ten CIMMYT subtropical quality protein maize populations.

Heterosis effects were significant only for plant height and, among its components, average heterosis was highly significant. Only average heterosis was significant for ear height. Miranda and Vencovsky (1984) also found average heterosis to be the only highly significant component of heterosis for plant and ear height.

Average plant size varied from 176 cm for Morocho Ayacuchano to 251 cm for Morocho Ecuatoriano (Table 11). The Mexican cultivars, Cacahuazintle, Chalqueño, and Conico 7, and the Colombian cultivar Cacao, had the shortest plant size. GCA effects (g_i) and cultivar effects (v_i) for all ten cultivars were highly significant. Negative estimates of GCA effects were for the Mexican cultivars and Morocho Ayacuchano. Morocho Ayacuchano had the largest negative GCA effects (-20.2) and cultivar effects (-39.4), whereas the largest positive GCA effects (16.6) and cultivar effects (36.0) were for Morocho Ecuatoriano (Table 11).

Only Conico 7 and Cacao showed positive and highly

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Table 11. Average plant height (cm) for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) and, cultivar heterosis effects (h_i)

		Plant	height	t		
	<u>Cultivar p</u>	<u>er se</u>	cross	es q _i	<u> </u>	<u> </u>
1.	Cacahuazintle	196	213	-11.6**	-18.6**	-2.3
2.	Chalqueño	200	213	-12.0**	-15.0**	-4.5*
з.	Conico 7	185	217	-7.3**	-29.7**	7.5**
4.	INIAP 153	224	235	13.6**	29.2**	-1.0
5.	Mor. Ecuat.	251	238	16.6**	36.0**	-1.4
6.	Cacao	210	227	3.8**	-4.9**	6.2**
7.	Cabuya	226	228	4.8**	11.3**	-0.9
8.	Blanco Urub.	232	228	5.4**	17.2**	-3.2
9.	Umutu	229	229	7.0**	13.9**	0.1
10.	Mor. Ayac.	176	206	-20.2**	-39.4**	-0.4
1	Mean					

 $LSD_{(0.05)}$ for cultivars per se: 15.4 cm. $LSD_{(0.05)}$ for cultivars in crosses: 5.1 cm. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

significant cultivar heterosis effects (7.5 and 6.2, respectively). The only negative and significant value was for Chalqueño (h_i =-4.5) (Table 11).

Negative values for GCA effects and cultivar effects suggest the presence of alleles for shorter plant size, which might be convenient if interest is focused on shorter plants. The crosses of Morocho Ayacuchano by Cacahuazintle and Chalqueño were, on the average, the shortest in plant

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height with 191 cm for each cross. The tallest plant size (260 cm) was obtained by the cross between the two Ecuatorian cultivars, INIAP 153 and Morocho Ecuatoriano (Table 12).

Extreme values for specific combining ability (SCA) effects were obtained in crosses between taller and shorter cultivars. The largest negative SCA estimates were for Cacao x Chalqueño (-9.2) and Cabuya x Blanco Urubamba (-8.8). Cacao x Morocho Ayacuchano (10.2) and Conico 7 x Cabuya (9.4) had the largest positive values for SCA effects (Table 12). Values for high parent (HP) heterosis were mostly negative (73%) whereas those for mid-parent (MP) heterosis were mostly positive (87%) (Table A8), indicating that the plant size of most F_1 crosses were in the direction of the taller parent.

For ear height the results were very similar to those of plant height. Among cultivars, the lower ear position was for Morocho Ayacuchano (89 cm), followed by Conico 7 (98 cm), Cacahuazintle (105 cm), and Chalqueño (107 cm) (Table 13). All these cultivars had negative and significant values for GCA effects and cultivar effects. The highest ear position was for Morocho Ecuatoriano (162 cm) and INIAP 153 (157 cm). These cultivars had values for GCA effects and cultivar effects of 15.7 and 12.7, and of 37.8 and 32.1, respectively.

	ultivars	1	2	3	4	5	6	7	8	9	10
1.	Cacahuaz.	:	200	199	219	233	217	213	224	223	191
2.	Chalqueño	0.2		196	225	230	206	224	223	219	191
3.	Conico 7	-5.8**	-8.0**		228	229	226	230	224	227	193
4.	INIAP 153	-6.7**	0.4	-1.8**	:	260	233	250	244	240	221
5.	Morocho Ecu	a.3.9**	1.9**	-3.6**	6.8**		239	247	239	253	215
6.	Cacao	1.6*	-9.2**	6.1**	-7.1**	-5.2**		224	241	237	217
7.	Cabuya	-3.3**	8.0**	9.4**	8.1**	1.8*	-7.7**		225	227	209
8.	Blanco Urub	. 6.9**	6.3**	2.4**	1.4	-6.1**	8.6**	-8.8**		230	204
9.	Umutu	3.8**	0.5	4.6**	-4.3**	5.7**	3.2**	-8.0**	-5.6*	*	210
10.	Morocho Aya	c0.8	-0.1	-3.3**	3.9**	-5.2**	10.2**	0.5**	-5.1*	* -0.0	

Table 12. Average plant height (cm) over seven locations (above diagonal) and specific combining ability effects (below diagonal) for 45 F_1 crosses among ten maize cultivars

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LSD_(0.05) for crosses: 15.4 cm. *,** significant at 0.05 and 0.01 probability levels, respectively.

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The mean ear height of crosses ranged from 98 cm for the cross between Cacahuazintle x Morocho Ayacuchano to 168 cm for INIAP 153 x Norocho Ecuatoriano (Table 14). The lowest value for SCA effects was for INIAP 153 x Cacao (-9.0) whereas the highest value for SCA effects was for Cacao x Morocho Ayacuchano (11.3). Negative and significant estimates for SCA effects were for crosses of Blanco Urubamba with Morocho Ecuatoriano (-6.4) and Cabuya 7 (-5.2). These crosses also had negative estimates for MP and HP heterosis (Table A10).

Table 13. Average ear height (cm) for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) , and cultivar heterosis effects (h_i)

		Ear 1	neight			
	<u>Cultivar p</u>	<u>er se</u>	cross	es q _i	v_i	<u> </u>
1.	Cacahuazintle	105	121	-9.3**	-19.5**	0.4
2.	Chalqueño	107	121	-9.8**	-17.3**	-1.2
3.	Conico 7	98	122	-8.0**	-26.9**	5.4**
4.	INIAP 153	157	141	12.7**	32.1**	-3.3*
5.	Mor. Ecuat.	162	143	15.7**	37.8**	-3.2*
6.	Cacao	119	133	3.8**	-5.9**	6.8**
7.	Cabuya	142	137	9.1**	17.6**	0.3
8.	Blanco Urub.	130	131	2.1**	5.7**	-0.7
9.	Umutu	136	133	4.1**	12.0**	-1.9
10.	Mor. Ayac.	89	111	-20.2**	-35.5**	-2.5
	Mean	124	129	· · _ · _ · · · · · · · · · · · ·		

LSD_(0.05) for cultivars: 14.5 cm. LSD_(0.05) for cultivars in crosses: 4.8 cm. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

C	<u>ultivars</u>	1	2	3	4	5	6	7	8	9	10
1.	Cacahuazintle		109	108	133	143	123	123	125	127	98
2.	Chalqueño	-1.4		106	130	133	121	135	131	122	99
3.	Conico 7	-4.1*	-5.2**	t	128	133	133	139	123	131	98
4.	INIAP 153	0.4	-2.4	-6.2**		168	137	157	147	143	123
5.	Morocho Ecua.	7.1**	-2.5	-4.0*	10.7**		141	156	141	152	123
6.	Cacao	-1.0	-2.7	8.0**	-9.0**	-7.6**	ł .	134	139	142	124
7.	Cabuya	5.8**	6.6**	* 9.1 ^{**}	5.7**	1.7	-8.0**	t	135	140	124
8.	Blanco Urub.	3.3**	9.6**	-0.5	3.1**	-6.4**	* 4.1**	-5.2*	*	129	109
9.	Umutu	2.9	-1.8	6.0**	-3.4*	2.7	4.9**	-2.7	-6.1**	t	111
10.	Morocho Ayac.	-1.5	-0.3	-3.2	1.1	-1.6	11.3*	* -1.4	-1.9	-2.5	

Table 14. Average ear height (cm) over seven locations (above diagonal) and speci-fic combining ability effects (below diagonal) for 45 F₁ crosses among ten maize cultivars

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LSD_(0.05) for crosses: 14.5 cm. *,** Significant at 0.05 and 0.01 probability levels, respectively.

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Root lodging and stalk lodging

The analysis of variance for each location for root and stalk lodging are presented in Tables All and Al3. The combined analysis of variance across locations indicated highly significant differences for locations, for entries, and for the location x entries interaction for both root and stalk lodging (Table 15). Cultivar effects were highly significant and their contribution to the total variability for entries was nearly double the contribution of heterosis effects. Heterosis was highly significant only for stalk lodging and specific heterosis was the only component showing significance. General combining ability (GCA) effects were highly significant for root and stalk lodging, indicating that additive gene effects were important in their expression. (Table 15).

The location x cultivar interaction effects and location x GCA interaction effects were highly significant for root and stalk lodging. No significance was detected for location x heterosis, but the interactions of locations and each component of heterosis were significant for stalk lodging, indicating a different response for stalk lodging of the cultivars and their crosses among locations.

Among cultivars, Cacao had the lowest percentage of root lodging (1.6%) with the Ecuatorian cultivars INIAP 153 (3.5%) and Morocho Ecuatoriano (3.5%) having little root

		Mean s	quares
source	df	Root lodging	Stalk lodging
Location (L)	6	9869.60**	2493.52**
Replication /L	7	256.72**	143.73**
Entry	54	102.40**	164.47**
Cultivar	9	375.50**	669.81**
GCA ^a	9	257.14**	369.64**
Heterosis (h)	45	47.78	63.40**
Average (Ah)	1	21.56	153.69
Cultivar (Ch)	9	72.45	62.61
Specific (Sh)	35	42.19	61.02**
L x entries	324	59.60**	48.50**
ĹхС	54	109.93**	115.39**
L X GCA	54	91.52**	79.07**
L x h	270	49.53	35.12
L x Ah	6	62.58	96.26**
L x Ch	54	63.49*	37.51*
x Sh	210	45.57	32.76*
Pooled error	378	44.41	26.17
C.V.(%) S.D.		92.93 6.66	74.25 5.12

Table 15. Combined analysis of variance across locations for root and stalk lodging (%) for ten cultivars of maize and their 45 diallel crosses

^a General combining ability.
*,** Significant at 0.05 and 0.01 probability levels, respectively.

lodging (Table 16). The highest percentage of root lodging was for the Mexican cultivars Cacahuazintle (8.9%), Chalqueño (12.5%), and Conico 7 (12.0%), which is not surprising because these cultivars are characterized by their poor radicular root system.

Table 16. Average root lodging (%) for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) , and cultivar heterosis effects (h_i)

	Root	lodgin	đ		
<u>Cultivar</u>	per se	cross	<u>es q_i</u>	v_i	<u> </u>
1. Cacahuazintle	2 8.87	9.07	2.05**	2.05**	1.02
2. Chalqueño	12.49	8.76	1.70**	5.67**	-1.13*
3. Conico 7	11.96	8.23	1.10**	5.14**	-1.46*
4. INIAP 153	3.46	6.89	-0.40*	-3.36**	1.28*
5. Mor. Ecuat.	2.38	6.38	-0.98**	-4.44**	1.24*
6. Cacao	1.55	5.52	-1.94**	-5.27**	0.69
7. Cabuya	7.65	5.21	-2.29**	0.83	-2.71**
8. Blanco Urub.	6.74	8.28	1.16**	-0.08	1.20*
9. Umutu	6.38	6.52	-0.82**	-0.44	-0.60
10. Mor. Ayac.	6.69	7.61	0.41*	-0.13	0.47
Mean	6.82	7.25			

LSD_(0.05) for cultivars per se: 4.9%. LSD_(0.05) for cultivars in crosses: 1.6%. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

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Negative values for GCA effects, which are desirable to reduce lodging, were obtained for Cabuya (-2.29), Cacao (-1.94), Umutu (-0.82), Morocho Ecuatoriano (-0.98), and INIAP 153 (-0.40). All these cultivars, except Cabuya, also had negative values for cultivar effects. Cabuya had the lowest cultivar heterosis effect ($h_i = -2.71$) whereas INIAP 153 (1.28) and Morocho Ecuatoriano (1.24) had the highest values (Table 16).

The average root lodging for crosses ranged from 2.7% for Cacao x Cabuya to 12.8% for Chalqueño x Blanco Urubamba. These crosses had specific combining ability effects of -0.32 and 2.66, respectively (Table 17). The crosses among Mexican cultivars had higher percentages of root lodging. Crosses among the Ecuatorian and Colombian cultivars had below average root lodging.

The cross between INIAP 153 x Blanco Urubamba had the lowest negative SCA effects (-2.48). Other crosses with low and negative SCA effects were Conico 7 x INIAP 153 (-2.37) and Cacahuazintle x Cacao (-2.32). These crosses had 5.5%, 5.6% and 5.0% of root lodging, respectively (Table 17).

Negative mid-parent heterosis was for 44% of the crosses. The range was between -47.8% (Chalqueño x Cabuya)) to 208.0% (Morocho Ecuatoriano x Cacao) (Table A12). The cultivar Cabuya had negative values for HP and MP heterosis

Table 17. Average root lodging (%) over seven locations (above diagonal) and speci-fic combining ability effects (below diagonal) for 45 F₁ crosses among ten maize cultivars

	<u>ultivars</u>	1	2	3	4	5	6	7	8	9	10
1.	Cacahuazintle		11.97	11.13	11.90	7.98	5.04	5.72	9.88	9.38	8.67
2.	Chalqueño	0.96		12.21	8.18	6.18	8.39	5.26	12.78	6.25	7.67
3.	Conico 7	0.72	2.15**	r	5.58	6.65	6.16	5.66	8.53	11.21	6.98
4.	INIAP 153	3.00'	*-0.37	-2.37**	r	5.15	3.89	5.31	5.53	6.49	10.01
5.	Morocho Ecuador	-0.34	-1.79**	-0.73	-0.72		6.05	4.74	8.81	4.24	7.61
6.	Cacao	-2.32	** 1.38*	-0.25	-1.02	1.72**	r	2.70	6.33	5.05	6.11
7.	Cabuya	-1.29	-1.40*	-0.41	0.75	0.76	-0.32		5.95	3.67	7.93
8.	Blanco Urubamba	a-0.58	2.66**	*-0.99	-2.48**	1.38*	-0.14	-0.17		7.80	8.94
9.	Umutu	0.90	-1.89**	* 3.67**	* 0.46	-1.21*	0.56	-0.47	0.21		4.62
10.	Morocho Ayac.	-1.04	-1.69*	*-1.79*	* 2.75**	0.93	0.39	2.56**	0.12	-2.22	t*

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LSD_(0.05) for crosses: 4.94%. *,** Significant at 0.05 and 0.01 probability levels, respectively.

in crosses with all cultivars except Morocho Ayacuchano.

The average percentage of stalk lodging for cultivars per se (7.8%) was higher than that of their crosses (6.7%) (Table 18). Cacahuazintle (19.4%), Chalqueño (11.6%), and Conico 7 (11.8%) had the highest percentages per se while INIAP 153 (3.1%), Morocho Ecuatoriano (3.7%), and Cacao (3.5%) had the lowest percentages of stalk lodging. GCA effects were also positive for Cacahuazintle, Chalqueño, Conico 7, Umutu, and Morocho Ayacuchano. Negative and significant GCA effects were obtained for INIAP 153 (-1.70), Morocho Ecuatoriano (-1.65), Cacao (-1.86), and Cabuya (-1.46).

Negative estimates of cultivar heterosis were obtained for Cacahuazintle (-2.79), Chalqueño (-1.79), and Cabuya (-0.51). Morocho Ayacuchano (1.10), Conico 7 (1.07), and Blanco Urubamba (0.82) had positive and significant cultivar heterosis effects.(Table 18).

Stalk lodging among crosses ranged from 2.2% (INIAP 153 x Cacao) to 16.8% (Cacahuazintle x Conico 7). These crosses had estimates of SCA effects of 0.89 and 4.08, respectively. (Table 19). In general crosses of Cacahuazintle and Conico 7 with the other cultivars resulted in higher percentages of stalk lodging. The lowest percentages of stalk lodging were obtained when INIAP 153 was crossed to the other cultivars except with the Mexican cultivars. The cross Conico 7 x

Table 18. Average stalk lodging (%) for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) , and cultivar heterosis effects (h_i)

	•	Stalk :	lodging			
	<u>Cultivar</u>	<u>per se</u>	crosses	<u> </u>	<u> </u>	<u> </u>
				_	_	-
1.	Cacahuazintle	e 19.40	9.34	2.99**	11.56**	-2.79**
2.	Chalqueño	11.64	6.85	0.19	3.80**	-1.71**
з.	Conico 7	11.82	9.40	3.06**	3.98**	1.07*
4.	INIAP 153	3.14	5.16	-1.70**	-4.70**	0.65
5.	Mor. Ecuat.	3.66	5.21	-1.65**	-4.18**	0.44
6.	Cacao	3.52	5.03	-1.86**	-4.32**	0.30
7.	Cabuya	5.94	5.38	-1.46**	-1.90**	-0.51
8.	Blanco Urub.	6.04	6.61	-0.07	-1.80**	0.82*
9.	Umutu	7.28	6.99	0.35*	-0.56	0.63
10.	Mor. Ayac.	5.93	6.81	0.14	-1.91**	1.10*
1	lean	7.84	6.68			

LSD_(0.05) for cultivars per se: 3.8%. LSD_(0.05) for cultivars in crosses: 1.3%. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

INIAP 153 had 13.5% of stalk lodging and the highest positive SCA effects (5.50).

Most values for high (87%) and mid-parent (73%) heterosis were negative. The highest positive HP heterosis values were for crosses between Morocho Ayacuchano with Blanco Urubamba (42.8%) and Umutu (53.8%) (Table A14). Morocho Ayacuchano crossed with Cacahuazintle had the lowest negative estimate of HP heterosis (-70.6%) and MP heterosis (-54.9%).

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Table 19. Average stalk lodging (%) over seven locations (above diagonal) and specific combining ability effects (below diagonal) for 45 F_1 crosses among ten maize cultivars

<u>Cultivars</u>	12	2:	34	5	6	7	8	9	10
1. Cacahuazintle	10.	93 16	.81 8.90	6.66	7.54	8.00	10.64	8.85	5.71
2. Chalqueño 1	.07*	7	.28 4.56	6.35	5.60	6.29	6.55	8.85	5.23
3. Conico 7 4	.08** -2	. 65**	13.54	8.14	5.11	4.98	10.27	10.12	8.36
4. INIAP 153 0	.93* -0	.61 5	.50**	2.81	2.23	2.77	2.93	4.01	4.74
5. Morocho Ecuador-1	.36** 1	. 13** 0	.05 -0.52		3.95	3.99	4.70	3.41	6.91
6. Cacao -0	.27 0	.59 -2	.77**-0.89*	0.78		6.47	4.26	5.07	5.01
7. Cabuya -0	.21 0	.88*-3	.30** -0.75	0.42	3.11**		5.31	5.16	5.49
8. Blanco Urubamba 1	.04* -0	.25 0	.60 -1.97**	-0.26	-0.49	0.16		6.24	8.62
9. Umutu -1	.17** 1	. 63** 0	.03 -1.31**	-1.97*	* -0.10	-0.41	-0.71		11.19
10. Morocho Ayac4	.10** -1	.78**-1	.52** -0.38	1.74*	*0.05	0.12 [.]	1.87**	4.02*	*

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LSD_(0.05) for crosses: 3.79%. *,** Significant at 0.05 and 0.01 probability levels, respectively.

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Ear volume, kernel depth and kernels per row

The analyses of variance for ear volume, kernel depth, and kernels per row are listed in Tables A15, A17, and A19, respectively. The combined analysis of variance across locations for ear volume (cm^3) , kernel depth (cm), and number of kernels per row (Table 20) showed highly significant differences for locations, for entries, and for the interactions of locations x entries. Most of the total variation among entry means was accounted for by cultivar effects (66%, 85%, and 74% for each trait, respectively). General combining ability effects (GCA) were also highly significant for the three traits. Specific heterosis was the most important component of heterosis, being highly significant for ear volume, kernel depth, and kernels number per row (Table 20). Cultivar heterosis was significant for kernel depth and kernels per row, whereas average heterosis was significant only for kernels per row.

The interactions of locations x cultivars, and locations x GCA were highly significant for each trait. Locations x heterosis interaction was significant only for ear volume. Locations x average heterosis showed statistical significance for the three traits. Higher values for ear volume might be desirable if breeding objectives are to improve ear appearance for better quality 'green corn'.

		Mea	an squares	
Source	df	Ear volume	Kernel depth	Kernels per row
Location (L)	6	447523.2**	3.339**	928.61**
Replication /L	7	6306.0**	0.190**	17.30**
Entry	54	16458.3**	0.302**	64.03**
Cultivars (C)	9	64954.6**	1.537**	283.01**
GCA ^a	9	40113.2**	1.141**	209.37**
Heterosis (h)	45	6759.1**	0.055**	20.23**
Average (Ah)	1	84450.6	0.147	230.65**
Cultivar (Ch)	9	4438.1	0.077**	20.25**
Specific (Sh)	35	5136.2**	0.047*	14.22**
L x entries	324	3572.0**	0.040**	6.91**
LxC	54	7784.9**	0.091**	12.47**
L X GCA	54	6075.0**	0.069**	11.20**
Lxh	270	2729.4*	0.030	5.80
L x Ah	6	16322.6**	0.176**	15.27**
L x Ch	54	3342.9*	0.035	6.41
L x Sh	210	2183.3	0.025	5.37
Pooled error	378	2165.8	0.027	4.23
C.V.(%) S.D.		17.1 46.5	14.440 0.165	9.17 2.20
Mean		272.1	1.145	23.97

Table 20. Combined analysis of variance across locations for ear volume (cm³), kernel depth (cm) and kernel number per row for ten maize cultivars and their 45 diallel crosses

^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

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Table 21. Average ear volume (cm^3) for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) , and cultivar heterosis effects (h_i)

		Ear v	olume	· · ·		
	<u>Cultivar p</u>	<u>er se</u>	crosses	<u> </u>	<u> </u>	<u>h_i</u>
1.	Cacahuazintle	257.7	284.4	8.4**	7.8*	4.5
2.	Chalqueño	238.2	279.4	2.7*	-11.6**	8.5*
з.	Conico 7	229.4	265.1	-13.4**	-20.5**	-3.1
4.	INIAP 153	268.4	274.7	-2.6*	18.5**	-11.8**
5.	Mor. Ecuat.	211.8	261.1	-17.9**	-38.1**	1.2
6.	Cacao	195.5	272.0	-5.6**	-54.4**	21.5**
7.	Cabuya	247.0	261.6	-17.4**	-2.9	-15.9**
8.	Blanco Urub.	318.8	303.3	29.6**	68.9**	-4.9
9.	Umutu	329.9	306.9	33.6**	80.1**	-6.4
10.	Mor. Ayac.	202.0	261.5	-17.4**	-47.9**	6.5

Mean 249.9 277.0

 $LSD_{(0.05)}$ for cultivars per se: 34.5 cm³. $LSD_{(0.05)}$ for cultivars in crosses: 11.5 cm³. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

Ear volume ranged from 195.5 cm^3 for Cacao to 329.9 cm^3 for Umutu (Table 21). The average mean ear volume for cultivars per se (249.9 cm^3) was lower than the mean for cultivars in crosses (277.0 cm^3). Blanco Urubamba and Umutu, both Peruvian cultivars, were the only ones with their mean in crosses lower than their mean per se. GCA effects were significant for all cultivars. Cultivar effects also were significant for all cultivars, but for Cabuya. Umutu and Blanco Urubamba had the highest values for both GCA effects (33.6 and 29.6), and for cultivar effects (80.1 and 68.9). Low and negative GCA effects and cultivar effects were for Morocho Ayacuchano (-17.4 and -47.9), and for Morocho Ecuatoriano (-17.9 and -38.1). Cacao had a -54.4 for cultivar effects although its performance in crosses and its contribution to heterosis was greater than the other cultivars. Cacao had a large and highly significant estimate of cultivar heterosis effects (21.5) (Table 21).

Specific combining ability (SCA) effects ranged from -35.1 for Chalqueño x Conico 7 to 30.0 for Conico 7 x Cabuya (Table 22). The cross with the highest ear volume was Chalqueño x Umutu (340.1 cm³); this cultivar cross had a high parent (HP) heterosis of 3.1%, and a mid-parent (MP) heterosis of 19.7% (Table A16). Positive and highly significant specific combining ability (SCA) effects were obtained for Blanco Urubamba in crosses with Cacahuazintle (24.5) and Conico 7 (23.3); the ear volume for these crosses was 339.5 cm³ and 316.5 cm³, respectively (Table 22). Blanco Urubamba had negative SCA effects when crossed with INIAP 153 (-32.8) and Cabuya (-21.3). The lowest ear volume was for INIAP 153 x Morocho Ecuatoriano (226.0 cm³), which had estimates of -30.5 for SCA effects, -15.8% for HP heterosis, and -5.9% for MP heterosis (Table A20).

Most crosses involving Cacahuazintle, Chalqueño, and
Table 22. Average ear volume (cm^3) over seven locations (above diagonal) and specific combining ability effects (below diagonal) for 45 F_1 crosses among ten maize cultivars

C	ultivars	1	2	3	4	5	6	7	8	9	10
1.	Cacahuaz.	2	257.1	247.6	293.9	273.9	290.0	266.1	339.5	320.0	271.9
2.	Chalqueño -	-31.0**		231.3	291.4	280.9	250.7	281.9	305.0	340.1	276.3
3.	Conico 7 -	-24.4**	-35.1**		275.8	242.2	271.5	276.3	316.5	293.3	231.8
4.	INIAP 153	11.1**	14.2**	14.7**	ŧ	226.0	254.0	271.5	271.2	321.8	266.9
5.	Morocho Ecu.	6.4	19.0**	-3.6	-30.5**	t	261.3	227.2	296.3	290.6	251.8
6.	Cacao	10.3**	-23.4**	13.5*	*-14.8**	7.8*		242.0	314.6	301.6	262.3
7.	Cabuya	-1.9	19.5**	30.0*	* 14.4**	-14.6*	*-12.0*	*	267.9	281.5	239.8
8.	Blanco Urub.	24.5**	-4.2	23.3*	*-32.8*	* 7.6*	13.7**	*-21.3**	*	339.4	279.3
9.	Umutu	1.0	26.8**	-4.0	13.8**	* -2.1	-3.4	-11.7*	* -0.8		273.6
10.	Morocho Aya.	3.9	14.0**	-14.4*	* 9.9*	* 10.0*	* 8.4*	-2.4	-9.9*	*-19.6*	*

LSD_(0.05) for crosses: 34.5 cm^3 . *,** Significant at 0.05 and 0.01 probability levels, respectively.

Conico 7 as one of the parents had positive HP heterosis percentages (Table A16). Nevertheless, the cross with the highest high-parent (29.9%) and mid-parent (32.0%) heterosis was Cacao x Morocho Ayacuchano. Only six crosses had negative MP heterosis. INIAP 153 x Blanco Urubamba had the lowest MP heterosis with -7.6%.

The average kernel depth was 1.12 cm for cultivars per se and 1.15 cm for cultivars in crosses (Table 23). The lowest kernel depths were for Cacao (0.82 cm), Morocho Ecuatoriano (0.88 cm), and Cabuya (0.94 cm). These cultivars also had negative values for cultivar effects. Blanco Urubamba (1.4 cm) and Umutu (1.3 cm) had the highest cultivar per se values (Table 23).

GCA effects were highly significant for the ten cultivars being positive for all Mexican (Cacahuazintle, Chalqueño and Conico 7) and Peruvian (Blanco Urubamba, Umutu and Morocho Ayacuchano) cultivars. Blanco Urubamba had the highest value for GCA effects (0.13) and cultivar effects (0.28), with cultivar heterosis effects almost zero ($h_i =$ -0.01) (Table 23).

The cross Cacahuazintle x Blanco Urubamba had the highest kernel depth (1.44 cm) and a value of 0.08 for SCA effects (Table 24). This combination had 14.1% and 3.1% for MP and HP heterosis, respectively (Table A22). The cross INIAP 153 x Blanco Urubamba had a kernel depth of 1.10 cm

Table 23. Average kernel depth (cm) for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) , and cultivar heterosis effects (h_i)

		Kerne.	<u>depth</u>	-		
	<u>Cultivar r</u>	<u>per se</u>	crosses	<u> </u>	<u> </u>	<u> </u>
						ىلەر بالە
1.	Cacahuazintle	e 1.13	1.21	0.07**	0.01	0.06**
2.	Chalqueño	1.21	1.25	0.11**	0.09**	0.06**
з.	Conico 7	1.18	1.20	0.05**	0.06**	0.02
4.	INIAP 153	1.16	1.12	-0.04**	0.06**	-0.06**
5.	Mor. Ecuat.	0.88	1.05	-0.11**	-0.24**	0.00
6.	Cacao	0.82	1.04	-0.12**	-0.30**	0.03*
7.	Cabuya	0.94	1.02	-0.15**	-0.18**	-0.06**
8.	Blanco Urub.	1.40	1.27	0.13**	0.28**	-0.01
9.	Umutu	1.30	1.19	0.04**	0.18**	-0.05**
10.	Mor. Ayac.	1.14	1.16	0.01*	0.02	0.00
	Vean	1.12	1.15			

LSD_(0.05) for cultivars per se: 0.12 cm. LSD_(0.05) for cultivars in crosses: 0.04 cm. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels.

and the lowest SCA effects (-0.15) and MP heterosis (-14.3%).

Chalqueño, in crosses with Morocho Ecuatoriano and Umutu, had the highest estimates for SCA effects (0.10 for each cross), with 1.24 cm and 1.40 cm kernel depth (Table 24). Also, Chalqueño x Morocho Ecuatoriano had the highest MP heterosis (18.9%) and a positive HP heterosis (2.7%) (Table A18).

Table	24.	Average k	ernel (depth	(cm)	over s	seven	locat	ions	(ab	ove	e diagona	al) and	l spe	ecific
		combining	j abili ⁴	ty eff	ects	(below	v diag	onal)	for	45	F ₁	crosses	among	ten	maize
		cultivars	÷								-				

Cultiva	ars	1	2	3	4		6	7	8	9	_10
1. Cacahu	laz.	1	.25 1	L.24	1.18	1.08	1.10	1.07	1.44	1.34	1.22
2. Chalqu	ieño -0	.08**	1	1.22	1.26	1.24	1.06	1.09	1.38	1.40	1.32
3. Conico	o7 −0	.03* -0	.09**		1.21	1.06	1.11	1.11	1.39	1.23	1.22
4. INIAP	153 0	.00 0	.04** (0.04**		0.99	1.03	1.05	1.10	1.16	1.09
5. Moroch	no EcuO	.03* 0	.10** -0	D.03 [*] -	-0.01		0.92	0.83	1.22	1.04	1.07
6. Cacao	c	0.00 -0	.08** (0.03	0.03**	0.00		0.86	1.21	1.08	1.03
7. Cabuya	a (0.00 -0	.02 (0.06**	0.09**	-0.05**	-0.02		1.11	1.00	1.03
8. Blanco	o Urub. (0.08** -0	.01 (0.05**-	-0.15**	0.05**	0.04**	-0.02		1.28	1.32
9. Umutu	c	0.07** 0	.10** -(0.02	0.00	-0.04**	0.01	-0.04**	-0.05**		1.19
10. Morocl	ho Aya(0.02 0	.05**	0.00 ·	-0.04**	0.02	-0.02	0.01	0.02	-0.02	

LSD_(0.05) for crosses: 0.12 cm. *,** Significant at 0.05 and 0.01 probability levels, respectively.

The average number of kernels per row for cultivars per se was 23 and ranged from 17 kernels per row for Morocho Ayacuchano to 27 kernels for Chalqueño (Table 25). Chalqueño had the highest estimates of GCA effects (2.44) and cultivar effects (3.97). Morocho Ayacuchano, Blanco Urubamba, and Umutu had the lowest values for GCA effects (-2.07, -2.01, and -0.40, respectively). Morocho Ayacuchano also had the lowest cultivar effect (-5.31) although it had the highest

Table 25. Average kernels per row for ten cultivars of maize per se and in crosses and estimates of GCA^a effects (g_i) , cultivar effects (v_i) , and cultivar heterosis effects (h_i)

Cultivar	Kernels	s per	row ses a	ν.	
	<u> </u>	01.00	<u></u>	<u> </u>	<u>**1</u>
1. Cacahuazintle	e 23	25	0.37**	0.26	0.24
2. Chalqueño	27	26	2.44**	3.97**	0.46*
3. Conico 7	26	25	1.42**	3.61**	-0.38*
4. INIAP 153	23	24	-0.32**	-0.10	-0.27
5. Mor. Ecuat.	21	24	0.17**	-1.60**	0.97**
6. Cacao	22	24	0.12*	-0.38*	0.31
7. Cabuya	23	23	0.26**	0.19	0.17
8. Blanco Urub.	22	22	-2.01**	-0.67**	-1.68**
9. Umutu	23	24	-0.40**	0.04	-0.42*
10. Mor. Ayac.	17	22	-2.07**	-5.31**	0.59**
Mean	23	24			

LSD_(0.05) for cultivars per se: 1.6 kernels. LSD_(0.05) for cultivars in crosses: 0.5 kernels. ^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels. cultivar heterosis effect (0.59), which would explain its good performance in crosses.

Chalqueño crossed with Morocho Ecuatoriano and with INIAP 153 had the greatest number of kernels per row (29 and 28, respectively), and also had the highest estimates for SCA effects (1.8 and 1.3) (Table 26). Crosses between cultivars from the same country had negative SCA effects, except for the cross Blanco Urubamba x Morocho Ayacuchano (0.6). The lowest SCA effect was for Chalqueño x Conico 7 (-2.0). This cross also had negative values for MP and HP heterosis, along with Cacao x Blanco Urubamba, Cabuya x Blanco Urubamba, and Blanco Urubamba x Umutu (Table A20). The highest HP heterosis was 12.1% for Cacahuazintle x Cabuya.

C	ultivars	_1	2	3	4	5	6	7	8	9	<u>10</u>
1.	Cacahuazintle		26	25	24	25	26	26	23	25	21
2.	Chalqueño	-0.8**		26	28	29	27	27	25	26	24
3.	Conico 7	-0.7**	-2.0**		25	26	27	27	24	25	23
4.	INIAP 153	0.1	1.3**	0.2		23	23	23	22	24	23
5.	Morocho Ecuador	-0.1	1.8**	0.2	-1.5**		24	25	22	24	22
6.	Cacao	1.1**	-0.1	1.5**	-0.8**	-0.0		23	21	23	24
7.	Cabuya	1.0**	0.5**	1.1**	-0.9**	0.2	-1.5**		22	24	23
8.	Blanco Urubamba	0.7**	0.1	0.6**	0.4*	-0.2	-1.3**	-0.9**		22	21
9.	Umutu	0.4*	-0.3	-0.2	0.3	0.2	-0.5**	0.3	-0.0		22
10.	Morocho Ayacucho	-1.7**	-0.5**	-0.8**	0.9**	-0.6**	1.8**	0.3	0.6**	-0.1	

Table 26. Average kernels number per row over seven locations (above diagonal) and specific combining ability effects (below diagonal) for 45 F_1 crosses among ten maize cultivars

LSD_(0.05) for crosses: 1.6 kernels. *,** Significant at 0.05 and 0.01 probability levels, respectively.

SUMMARY AND CONCLUSIONS

Diallel crosses among ten cultivars of highland tropical maize were made at Cajamarca, Peru, during the growing season 1990-1991. The ten cultivars included were Cacahuazintle, Chalqueño, and Conico 7 from Mexico, INIAP 153 and Morocho Ecuatoriano from Ecuador, Cacao and Cabuya from Colombia, and Blanco Urubamba, Umutu, and Morocho Ayacuchano from Peru.

Eight paired rows of 22 plants per row were used to produce the crosses. At harvest, ears belonging to the same cross were hand shelled and bulked. Seed for making crosses and for evaluation per se were obtained from the International Center for Maize and Wheat Improvement (CIMMYT) for the Mexican cultivars, and from the corresponding National Maize Program for the Colombian, Ecuatorian, and Peruvian cultivars.

The ten cultivars, their 45 F_1 crosses, and a local check were evaluated in a 7 x 8 rectangular lattice with two replications during the 1991-1992 growing season at seven locations: Santa Catalina (2950 m.a.s.l.) and Chuquipata (2410 m.a.s.l.) in Ecuador; Pairumani (2580 m.a.s.l.) in Bolivia; Baños del Inca (2754 m.a.s.l.), Pampa (2650 m.a.s.l.), Anta (2650 m.a.s.l.), and Jangas (2700 m.a.s.l.) in Peru.

The experimental unit was a two-row plot, each row included 11 hills with two plants per hill. The distance between rows and hills was 0.80 m and 0.50 m, respectively, to give a plant stand equivalent to 50000 plants per hectare.

Analyses of variance per location and combined across locations were performed for the following traits: grain yield (t/ha) adjusted to 15% humidity, 50% female flowering (days), grain moisture content (%), plant height (cm), ear height (cm), root lodging (%), stalk lodging (%), ear volume (cm³), kernel depth (cm), and number of kernels per row. The total variability among entries (cultivars and their 45 F_1 crosses) was partitioned following the analysis II and III of Gardner and Eberhart (1966). A mixed model was used with locations considered as a random effects and cultivars considered as fixed effects.

Highly significant differences for locations, for entries, and for the interaction locations x entries in all traits were detected in the combined analysis of variance across locations. Additive gene effects seemed of greater importance in the expression of all traits except yield because of the highly significant cultivar effects and general combining ability (GCA) effects, which accounted for most of the total variability among entries and among crosses, respectively. Heterosis effects were significant

for female flowering, plant height, stalk lodging, ear volume, kernel depth, and kernel number per row. Specific ' combining ability (SCA) effects were the more important component of heterosis, though they showed no statistical significance for grain moisture content, plant height, ear height, and root lodging.

For yield, cultivar effects and GCA effects were highly significant. Heterosis effects (75%), however, were more important in their contribution to the total variability among entries. SCA effects accounted for 58% and GCA accounted for 42% of the variation among crosses, suggesting that nonadditive gene effects were more important than additive effects in the expression of heterosis of yield. All three components of heterosis were significant for grain yield.

The interactions of locations x cultivar effects and of locations x GCA effects were highly significative for all characteristics considered in this study. The location x heterosis interaction was significant only for yield, grain moisture content, and ear volume.

All cultivars had greater yields in crosses compared with their yields per se, ranging from 3.46 t/ha for crosses with Cacao as one parent to 0.69 t/ha for crosses with Blanco Urubamba as one parent. The cultivar Cacao had the lowest yield per se (3.22 t/ha) but Cacao had the highest

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cultivar heterosis effect (1.06) which was because of its excellent combining ability. Average yield of INIAP 153 and Blanco Urubamba was 5.76 t/ha per se, and they also had the highest cultivar effects (1.12). INIAP 153 and Blanco Urubamba had significant estimates of GCA effects, but they had a relative low performance in crosses compared with the other cultivars as indicated by their negative cultivar effects. Cacahuazintle and Conico 7 had negative values for both GCA (-0.08 and -0.04) and cultivar effects (-0.85 and -0.61) but had positive and highly significant cultivar heterosis (0.34 and 0.26, respectively). The lowest yield in crosses was for Morocho Ayacuchano (5.43 t/ha), which also yielded poorly as cultivar per se (3.97 t/ha) and had the lowest value for cultivar heterosis (-0.72).

Heterosis for yield, expressed as percentage of the mid-parent (MP) value, was positive for all crosses. High parent (HP) heterosis was negative for only four of the 45 crosses. In this study, crosses between cultivars from the same country tended to express less heterosis than crosses between cultivars from different countries. Negative HP heterosis was obtained by Blanco Urubamba x Morocho Ayacuchano (-10.06%), Umutu x Morocho Ayacuchano (-10.63%), and INIAP 153 x Morocho Ecuatoriano (-10.94%). INIAP 153 x Morocho Ecuatoriano was the lowest yielding cross at 5.13 t/ha. Crosses among Cacahuazintle, Chalqueño, and Conico 7

with Cacao, Morocho Ecuatoriano, and Cabuya ranked among the top ten crosses for HP heterosis. Cabuya x Blanco Urubamba (7.37 t/ha) and INIAP 153 x Umutu (7.55 t/ha) had 28.0% and 31.1% HP heterosis, respectively. Cacao x Cacahuazintle (8.01 t/ha) had the highest yield among crosses with 111.2% heterosis over Cacahuazintle, the highest yielding parent of this cross.

The cultivars considered in this study can be grouped in earlier flowering cultivars, 76 to 85 days, (Cacahuazintle, Chalqueño, Conico 7, and Morocho Ayacuchano), medium late flowering cultivars, 102 to 108 days, (INIAP 153, Cabuya, Blanco Urubamba, and Umutu), and later, 119 and 121 days, for Cacao and Morocho Ecuatoriano, respectively. The earlier flowering group was characterized by having shorter plant height (176 cm to 200 cm), and ear height (89 cm to 107 cm). The late and medium-late groups were taller in height (210 cm to 251 cm), and had a higher ear placement (119 cm to 157 cm). Cacahuazintle, Chalqueño, and Conico 7 had the greatest incidence of root lodging (8.87%, 12.49%, and 11.96%, respectively), and stalk lodging (19.40%, 11.64%, and 11.82%, respectively). For the other cultivars root lodging ranged from 1.55% (Cacao) to 7.65% (Cabuya). and stalk lodging ranged from 3.14% (INIAP 153) to 7.28% (Umutu).

For female flowering, 87% of the crosses expressed

negative MP heterosis. Crosses involving Cacahuazintle, Morocho Ecuatoriano, Cacao, and Umutu required fewer number of days to 50% female flowering, while crosses that included INIAP 153 and Morocho Ayacuchano required greater number of days to 50% female flowering. The cross Cacahuazintle x Umutu was among the earliest (86 days) for female flowering and had the lowest MP heterosis of -8.27%.

Cultivar heterosis and specific combining ability (SCA) effects were not significant for grain moisture content, plant height, ear height, and stalk lodging. When these parameters are not significant, inferences about the genetic potential of the cultivars can be based solely on cultivar effects (Miranda and Vencovsky, 1984). In this respect, Cacahuazintle, Chalqueño, Cacao, and Morocho Ayacuchano had negative and significant cultivar effects for plant height and ear height. The three Mexican cultivars and Morocho Ayacuchano also had negative cultivar effects for grain moisture content. For root lodging, the cultivars Cacao, INIAP 153, and Morocho Ecuatoriano are expected to have lower incidence of root lodging in crosses, whereas these same cultivars, together with Cabuya and Umutu, would have lower incidence of stalk lodging.

Values for MP heterosis were mostly negative among crosses (84%) for grain moisture content. For plant height and ear height, 13% and 27% of all crosses, respectively,

had negative MP heterosis. For root lodging, values of MP heterosis ranged from -47.8% for the cross Chalqueño x Cabuya, to 208.0% for Morocho Ecuatoriano x Cacao; these two cultivars had the lowest incidence of root lodging per se. MP heterosis for stalk lodging was between -54.9% (Cacao x Morocho Ayacuchano) and 81.0% (Conico 7 x INIAP 153); 44% and 73% of the crosses had negative MP heterosis for both root and stalk lodging.

Blanco Urubamba (318.0 cm³) and Umutu (329.9 cm³) had the highest ear volume among cultivars, and the highest values for cultivar effects (68.9 and 80.1, respectively). The lowest ear volume was for Cacao (195.6 cm³), Morocho Ayacuchano (202.0 cm³), and Morocho Ecuatoriano (211.8 cm³); these cultivars had estimates of -54.4, -47.9, and 38.1 for cultivar effects. Forty-nine percent of the crosses had positive HP heterosis. Crosses between Cacahuazintle, Chalqueño, and Conico 7 with Blanco Urubamba and Umutu had the highest ear volume.

Blanco Urubamba (1.40 cm) and Umutu (1.30 cm) had the highest values for kernel depth, and they also had the highest values for cultivar effects (0.28 and 0.18, respectively). Morocho Ecuatoriano, Cacao, and Cabuya had values lower than one centimeter, and they also had negative and significant cultivar effects. Cacahuazintle and Chalqueño had the same positive and significant cultivar

heterosis effects (0.06); therefore, crosses involving these cultivars should result in a greater kernel depth. Positive HP heterosis was obtained in 31% of the crosses for kernel depth. The cross with the best heterotic response for kernel depth was Chalqueño x Morocho Ayacuchano (1.32 cm), with 9.4% HP heterosis.

The average number of kernels per row was 23, ranging from 17 (Morocho Ayacuchano) to 27 (Chalqueño). Cacahuazintle, Chalqueño, and Conico 7 had the highest positive GCA effects (0.37, 2.44, and 1.42, respectively). These cultivars also had positive cultivar effects and their crosses were among those with the highest HP heterosis. Blanco Urubamba and Umutu had negative GCA effects and cultivar heterosis. Crosses involving Blanco Urubamba had either low or negative HP heterosis. Fifty percent of crosses were above the highest parent. Cacahuazintle x Cabuya had the highest HP heterosis (12.1%).

Cacahuazintle, Chalqueño, and Conico 7 had a similar heterotic pattern and could be intermated to form a single population for recurrent selection. These cultivars flowered at the same time and had similar plant and ear heights. For yield Cacahuazintle and Conico 7 had negative GCA effects and cultivar effects but for Chalqueño these effects were positive and highly significant which suggest gains in yield during selection. The inclusion of Morocho Ayacuchano within

this group would be useful for improving resistance to root and stalk lodging, because Cacahuazintle, Chalqueño, and Conico 7 had the highest percentages of root and stalk lodging. Morocho Ayacuchano had negative cultivar effects for root and stalk lodging.

The Mexican cultivars generally showed excellent combining ability for all traits. Their crosses were among the better crosses for greater yields, earliness in flowering, shorter plants, less lodging, higher ear volume, better kernel depth, and greater number of kernels per row. Cacahuazintle crossed with Cacao was first in yield, and had the highest HP heterosis for yield. Cacahuazintle with Umutu for female flowering, with INIAP 153 for plant height, and with Morocho Ayacuchano for stalk lodging, ranked first, third, and first, respectively, for mid-parent heterosis.

Another group could be formed by intercrossing INIAP 153, Blanco Urubamba, and Umutu. These cultivars had the highest yields per se and had similar female flowering dates. Their highly significant GCA effects and cultivar effects for yield would allow progress towards the increase of alleles favoring higher productivity in a recurrent selection scheme. Besides, these cultivars exhibited negative and significant GCA and cultivar effects for root and stalk lodging. In addition, they also had the highest per se values for ear volume and kernel depth, with highly

significant GCA and cultivar effects for these traits. If the breeding objectives consider these characteristics, genetic gains should be achieved.

Among the medium late cultivars, the cross Cabuya x Blanco Urubamba was the most promising. These two cultivars had similar days to female flowering, and their F_1 cross yielded 7.37 t/ha with 28% HP heterosis. Also, MP heterosis for this cross was negative for days to female flowering, plant height, ear height, root lodging, and stalk lodging. Cabuya combines well with INIAP 153 (6.71 t/ha, and 16.5% HP heterosis), and with Umutu (7.04 t/ha, and 24.1%) HP heterosis.

Cacao had excellent combining ability for yield. Five of Cacao's crosses were among the top ten in yield, but Cacao and Morocho Ecuatoriano were the latest in flowering; they were 11 and 13 days later than INIAP 153 and Cabuya. Morocho Ayacuchano had poor performance per se in most traits, perhaps due to lack of adaptation to the environments in which the experiments were conducted. Nevertheless, it performed well in crosses for plant height, stalk lodging, ear volume, and kernel depth.

REFERENCES CITED

- Baker, R. J. 1978. Issues in diallel analysis. Crop Sci. 18:533-536.
- Beal, W. J. 1880. Rep. Michigan Board of Agriculture. pp. 287-288
- Brieger, F. G. 1950. The genetic basis of heterosis in maize. Genetics 35:420-444.
- Bruce, A. B. 1910. The Mendelian theory of heredity and the augmentation of vigor. Science 32:627-628.
- Collins, G. N. 1909. The importance of broad breeding in corn. Bureau of Plant Breding 141:33-34.
- Collins, G. N. 1921. Dominance and the vigor of first generation hybrids. Am. Nat. 55:116-133.
- Comstock, R. L.; H. F. Robinson; and P. H. Harvey. 1949. A breeding procedure designed to make maximun use of both general and specific combining ability. Agronomy J. 41:360-367
- Crossa, J.; C. O. Gardner; and R. Mumm. 1987. Heterosis among populations of maize (<u>Zea mays</u> L.) with different levels of exotic germoplasm. Theor. Appl. Genet. 73:445-450.
- Crossa, J.; S. Taba; and E. J. Wellhausen. 1990. Heterotic patterns among Mexican races of maize. Crop Sci. 30:1182-1190.
- Darwin, C. I. 1987. The effects of cross and self fertilization in the vegetable kingdom. Appleton, New York.
- East, E. M. 1909. The distinction between development and heredity in inbreeding. American Naturalist 43:173-181.

East, E. M. 1936. Heterosis. Genetics 21:375-397.

East, E. M.; and H. K. Hayes. 1912. Heterozygosis in evolution and in plant breeding. USDA Bureau of PLant Breeding. Bul. 243:1-58.

- Galarza, M. 1981. Variedades de maiz para la sierra ecuatoriana. Bol. Divul. 19. Est. Exp. 'Santa Catalina'. Quito, Ecuador.
- Gardner, C. O. 1965. Teoria genética estadística aplicable a las medias de variedades, sus cruces y poblaciones afines. Fitotecnia Latinoamericana 1:11-22.
- Gardner, C. O.; and S. A. Eberhart. 1966. Analysis and interpretation of the variety cross diallel and related populations. Biometrics 22:439-452.
- Gardner, C. O. 1967. Simplified methods for estimating constants and computing sum of squares for diallel cross analysis. Fitotecnia Latinoamericana 4:1-12.
- Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Bio. Sci. 9:463-493.
- Genter, C. F.; and S. A. Eberhart. 1974. Performance of original and advanced maize populations and their diallel crosses. Crop Sci. 14:881-885.
- Grobman, A.; W. Salhuana; and R. Sevilla; with P.C. Mangelsdorf. 1961. Races of maize in Peru. Pub. 915. NAS-NRC. Washington, D. C.
- Hallauer, A.; and J. B. Miranda. 1988. "Quantitative Genetics in Maize Breeding". 2nd ed. Iowa State University Press. Ames, Iowa.
- Hallauer, A.; W. Russell; and K. Lamkey. 1988. In "Corn and Corn Improvement" (G. F. Sprague and J. W. Dudley, eds.). pp. 463-565. Agronomy Monograph 18. ASA, Madinson, Wisconsin.
- Hayman, B. I. 1954a. The analysis of variance of diallel tables. Biometrics 10:235-244.
- Hayman, B. I. 1954b. The theory and analysis of diallel crosses. Genetics 39:789-809.
- Hull, F. H. 1945. Recurrent selection for specific combining ability in corn. J. Ame. Soc. of Agron. 37:134-145.
- Jinks, J. L. 1955. A survey of the genetical basis of heterosis in a variety of diallel crosses. Heredity 9:223-238.

- Jones, D. F. 1917. Dominance of linked factors as a means of accounting for heterosis. Genetics 2:466-478.
- Jones, D. F. 1918. The effects of inbreeding and crossbreeding upon development. Connecticut Agric. Exp. Sta. Bul. 207:5-100.
- Jones, R. M. 1965. Analysis of variance on the half diallel table. Heredity 20:117-121.
- Kauffman, K. D.; C. W. Crum; and M. F. Lindsey. 1982. Exotic germplasm in a corn breeding program. In "Proc. 18th annual Illinois Corn Breeders School". pp. 6-39. Univ. of Illinois. Urbana, Champaigne, Illinois.
- Keeble, F.; and C. Pellew. 1910. The mode of inheritance of stature and time of flowering in peas (<u>Pisum sativum</u>). J. Genetics 1:47-56.
- Kempthorne, O. 1956. The theory of diallel cross. Genetics 41:451-459.
- Lonnquist, J. H.; and C. O. Gardner. 1961. Heterosis in intervarietal crosses in maize. Crop Sci. 1:179-183.
- Miranda, J. B.; and R. Vencovsky. 1984. Analysis of diallel crosses among open-pollinated varieties of maize (Zea mays L.). Meydica 29:217-234.
- Moll, R. H.; W. Salhuana; and H. F. Robinson. 1962. Heterosis and genetic diversity in variety crosses of maize. Crop Sci. 2:197-198.
- Moll, R. H.; J. H. Lonnquist; J. V. Fortuna; and E. C. Johnson. 1965. The relation of heterosis and genetic divergence in maize. Genetics 52:139-144.
- Mungoma, C.; and L. M. Pollak. 1988. Heterotic pattern among ten corn belt and exotic maize populations. Crop Sci. 28:500-504.
- Pandey, S.; and C. O. Gardner. 1992. Recurrent selection for population, variety, and hybrid improvement in tropical maize. Advances in Agronomy 48:1-87.
- Paterniani, E.; and J. H. Lonnquist. 1963. Heterosis in interracial crosses of corn (<u>Zea mays</u> L.). Crop Sci. 3:504-507.

Paterniani, E. 1964. Value of exotic and local inbred lines of corn. Fitotecnia Latinoamericana 1:15-22.

- Pollak, L. M.; S. Torres-Cardona; and A. Sotomayor-Rios. 1991. Evaluation of heterotic patterns among Caribbean and tropical x temperate maize populations. Crop Sci. 31:1480-1483.
- Richey, F. 1922. The experimental basis for the present status of corn breeding. J. Ame. Soc. of Agron. 14:1-17.
- Richey, F. 1946. Hybrid vigour and corn breeding. J. Ame. Soc. of Agron. 38:833-841.
- Roberts, C. M.; U. J. Grant; R. Ramirez; W. H. Hatheway; and D. L. Smith; with P. C. Mangelsdorf. 1957. Races of maize in Colombia. Pub. 510. NAS-NRC. Washington, D. C.
- Robinson, H. F.; and R. H. Moll. 1965 Procedimientos útiles para mejorar el comportamiento de cruces intervarietales. Fitotecnia Latinoamericana 2:39-56.
- Sedcole, J. R. 1981. A review of the theories of heterosis. Egypt. J. Genet. Cytol. 10:117-146.
- Shull, G. H. 1908. The composition of a field of maize. American Breeders' Assoc. Rep. 4:296.
- Shull, G. H. 1909. A pure-line method in corn breeding. American Breeders' Assoc. Rpt. 5:51-59.
- Shull, G. H. 1914. Duplicate genes for capsule form in Bursa bursapastoris. Z. Ind. Abst. Ver. 12:97-149.
- Sprague, G. F.; and L. A. Tatum. 1942. General vs specific combining ability in single crosses of corn. J. Ame. Soc. of Agron. 34:923-932.
- Sprague, G. F. 1946. The experimental basis for hybrid maize. In "Heterosis in maize: theory and practice". Monographs on theoretical and applied genetics (Frankel Springer - Verlog - Berlin, eds.). Biological Reviews 21:101-120.
- Sprague, G. F. 1953. Heterosis. In "Growth and differentation in plants" (W. E. Loomis, eds). pp. 113-136. Iowa State University Press. Ames, Iowa.

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- Sprague, G. F. 1984. Organization of breeding programs. In "Proc. 20th Annual Illinois Corn Breeders School". pp. 20-31. University of Illinois. Urbana, Champaign-Illinois.
- Timothy, D. H.; W. H. Hatheway; U. J. Grant; M. Torregroza; D. Sarria; and D. Varela. 1963. Races of maize in Ecuador. Pub. 975. NAS-NRC. Washington, D. C.
- Vasal,S. K.; G. Srinivasan; S. Pandey; F. Gonzalez; J. Crossa; and D. Beck. 1993a. Heterosis and combining ability of CIMMYT's quality protein maize germplasm: I. lowland tropical. Crop Sci. 33:46-51.
- Vasal, S. K.; Srinivasan; F. Gonzales; D. L. Beck; and J. Crossa. 1993b. Heterosis and combining ability of CIMMYT's quality protein maize germplasm: II. Subtropical. Crop Sci. 33:51-57.
- Wellhausen, E. J.; L. M. Roberts; and X. Hernandez; with P. C. Mangelsdorf. 1952. Races of maize in Mexico. Bussey Institution. Harvard University.

Whaley, W. G. 1944. Heterosis. Bot. Rev. 10:461-498.

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			Mear	n squares	for each	locatio	n	
Source	df	Baños	Pampa	Anta	Jangas S.	Catalina	Chuquipata	Pairumani
Replication	1	1.34	0.01	11.71	0.52	43.47**	12.64**	0.53
Entries	54	7.50**	1.30**	7.61**	3.28	6.06**	4.50**	5.82**
Varieties	9	17.06**	3.89**	7.55*	4.74	22.54**	8.12**	9.33**
GCA ^a	9	10.80**	3.32**	8.27**	5.53**	12.46**	7.62**	7.46**
Heterosis	45	5.59**	0.78*	7.62**	2.99	2.76**	3.77**	5.11**
Average	1	102.35**	7.10**	43.69**	54.55**	25.01**	69.06**	82.53**
Variety	9	4.25	0.59	6.87*	2.25	3.12*	1.11	1.07
Specific	35	3.17	0.64	6.78**	1.71	2.04*	2.60**	3.94**
Error	54	2.09	0.43	2.89	2.61	1.15	0.85	1.39
C.V. (%)		15.76	35.76	23.75	33.74	14.59	19.84	15.88
S.D. Mean		1.45 9.18	0.66 1.85	1.70 7.17	1.61 4.78	1.07 7.35	0.92 4.65	1.18 7.44

Table A1. Analysis of variance for grain yield (t/ha) for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combinig ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

<u>Cu</u>	ltivars	1	2	3	4	5	6	7	8	9	10
1.	Cacahuazintle		3.6	30.0	18.2	50.3	111.2	34.5	11.3	17.6	35.7
2.	Chalqueño	17.6		1.1	20.8	32.8	44.8	45.8	24.8	38.6	6.0
3.	Conico 7	34.0	11.5		34.5	52.5	86.7	41.5	26.7	13.7	7.1
4.	INIAP 153	42.7	30.1	58.4		-10.9	14.7	16.5	9.8	31.1	15.1
5.	Morocho Ecuador	57.6	43.8	55.2	3.2		43.2	18.0	-4.1	21.8	15.6
6.	Cacao	128.8	75.3	107.9	47.0	61.9		12.5	8.3	12.6	65.6
7.	Cabuya	53.8	47.8	57.6	24.0	29.5	37.6		28.0	24.2	12.0
8.	Blanco Urubamba	34.3	31.1	48.2	9.8	11.1	38.8	36.3		14.2	-10.1
9.	Umutu	41.0	48.3	33.0	32.2	40.2	43.8	31.1	15.1		-10.6
10.	Morocho Ayacucho	38.8	17.6	8.0	36.3	18.5	83.0	25.6	6.5	5.1	

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Table A2. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for grain yield averaged over seven locations for 45 F₁ crosses among ten maize cultivars

			Mean	squares	for each	location		
Source	df	Baños	Pampa	Anta	Jangas	S.Catalina	Chuquipata	Pairumani
Replication	1	1.8	27.5	8.2	96.4	1.5	6.6	10.5
Entries	54	251.6**	136.0**	202.3**	339.1**	331.5**	222.1**	318.3**
Varieties	9	1413.4**	731.3**	1104.9**	1466.2**	1878.1**	1193.3**	1753.8**
GCA ^a	9	861.5**	456.1**	681.6**	990.1**	1089.6**	787.9**	1068.3**
Heterosis	45	19.3**	17.0*	21.8*	113.7	22.1**	27.8**	31.1**
Average	1	201.1**	1.6	10.5	243.9	275.1**	279.6**	215.4**
Variety	9	18.7**	17.4	37.6**	44.2	37.8**	15.4	32.2*
Specific	35	14.2**	17.3*	18.0	127.9	10.8**	23.9**	25.6*
Error	54	2.7	9.8	12.3	117.8	5.0	7.9	12.3
C.V.(%)		10.0	3.2	3.4	11.0	2.2	3.3	3.7
S.D. Mean		1.6 94.5	3.1 97.8	3.5 102.3	10.8 99.0	2.2 102.6	2.8 85.1	3.5 94.0

Table A3. Analysis of variance for female flowering (days) for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

	Cultivars	1	2	3	4	5	6	7	8	9	10
1.	Cacahuazintle		-0.7	-2.3	-10.3	-19.6	-18.8	-14.7	-13.8	-16.4	-6.6
2.	Chalqueño	-0.3		-1.7	-9.5	-16.0	-16.5	-11.3	-12.5	-12.4	-5.7
3.	Conico 7	-1.5	-0.7		-16.6	-21.9	-15.8	-13.2	-12.1	-12.8	-7.2
4.	INIAP 153	-2.5	1.5	-5.7		-2.4	-9.6	-0.7	-1.3	-8.5	-11.8
5.	Morocho Ecuador	-5.5	-1.0	-7.2	2.7		-6.8	-9.0	-13.9	-13.5	-22.7
6.	Cacao	- 5.1	-2.1	-0.5	-5.0	-6.1		-9.0	-12.3	-11.7	-17.0
7.	Cabuya	-4.5	-0.4	-1.7	-0.6	-3.7	-4.4		-4.3	-6.3	-15.2
8.	Blanco Urubamba	-5.7	-4.0	-2.7	1.1	-6.7	-5.6	-1.8		-4.5	-12.4
9.	Umutu	-8.3	-3.5	-3.2	-6.7	-6.6	-5.4	-4.3	-4.1		-13.9
10.	Morocho Ayacuch	0-1.3	-0.7	-3.2	3.5	-5.0	1.5	-0.4	0.6	-0.7	

Table A4. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for female flowering averaged over seven locations for 45 F_1 crosses among ten maize cultivars

			Mea	n squares	for each	location		
Source	df	Baños	Pampa	Anta	Jangas	S.Catalina	Chuquipata	Pairumani
Replication	1	2.3	3.2	5.2	19.2	88.6**	0.0	90.2*
Entries	54	94.3**	188.4**	25.3**	41.0**	56.8**	34.3**	58.3**
Varieties	9	531.0**	976.3**	97.3**	183.5**	168.4**	41.3**	260.3**
GCA ^a	9	328.9**	615.5**	54.9**	136.0**	182.3**	36.6**	172.8**
Heterosis	45	7.0	30.8	10.9*	12.5	34.5**	32.9**	17.9
Average	1	27.6*	26.9	1.9	4.6	215.7**	26.5*	48.8
Variety	9	12.1	36.4	17.3	8.0	51.4**	28.8**	15.9
Specific	35	5.0	29.4	9.6	13.9	24.9**	34.2**	17.5
Error	54	6.7	22.5	6.3	11.1	9.9	4.8	20.7
C.V. (%)		7.0	13.9	7.3	10.3	11.8	11.2	23.2
s.d. Mean		2.6 37.1	4.7 34.0	2.5 34.6	3.3 32.2	3.1 26.6	2.2 19.5	4.5 19.6

Table A5. Analysis of variance for grain moisture content (%) for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combining ability. *,** Significant at 0.05 and 0.01 probability level, respectively.

Cu	ltivars	1	2	3	4	5	6	7	8	9	10
4	Cacabuagintle		_5 0	-E 0	-00 5	-22 0	-19 7	-10 7	-22 0	-10 2	_0 7
1.			-2.0	-3.9	-22.5	-23.0	-13./	-12.7	-23.0	-10.2	-0./
2.	Cnalqueno	-1.5		-13.8	-22.3	-20.3	-15.8	-13.0	-24.0	-12.6	1.8
3.	Conico 7	-3.4	-7.6		-24.4	-33.7	-20.1	-14.5	-23.1	-22.1	-18.3
4.	INIAP 153	-5.9	-9.1	-6.4		-2.5	-8.6	-5.2	-2.9	-3.0	-6.7
5.	Morocho Ecuador	-4.8	-4.9	-16.4	-0.2		-12.7	-15.4	-6.9	-9.7	-21.9
6.	Cacao	0.4	-5.7	-5.1	-3.9	-6.0		-9.7	-11.3	-3.9	-13.0
7.	Cabuya	1.2	-3.1	1.3	0.2	-8.7	-9.3		-14.1	-6.4	-16.9
8.	Blanco Urubamba	-5.6	-10.5	-2.8	-0.3	-6.7	-4.4	-7.0		-8.6	-19.8
9.	Umutu	-5.0	-2.3	-7.5	2.2	-2.6	-3.7	-6.2	-1.2		-13.2
10.	Morocho Ayacucho	-1.3	5.5	-9.6	3.7	-9.5	-6.0	-10.3	-6.9	-6.0	

Table A6. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for grain moisture content (%) averaged over seven locations for 45 F₁ crosses among ten maize cultivars

		Mean squares for each location									
Source	df	Baños	Pampa	Anta	Jangas S.	Catalina	Chuquipata	<u>Pairumani</u>			
Replication	1	42.0	3852.7**	1649.8	796.5	2953.6**	10486.1**	667.6			
Entries	54	1281.3**	946.3**	816.6	983.5**	719.8**	787.8*	2967.7**			
Varieties	9	5699.2**	4916.5**	944.4	3761.1**	3526.3**	3016.7**	13914.5**			
GCA ^a	9	3336.2**	3311.6**	504.6	2144.9**	2011.8**	2686.4**	11329.6**			
Heterosis	45	397.7**	211.6	791.0	427.9	158.5	342.1	778.4			
Average	1	1199.3**	51.7	737.0	4125.3**	321.6	624.5	3711.9*			
Variety	9	342.0	138.8	1408.9	348.7	276.0	288.8	947.7			
Specific	35	389.1*	234.9	634.9	342.7	124.9	347.7	651.0			
Error	54	195.9	291.7	1012.2	302.5	134.1	420.1	673.5			
C.V.(%)		5.6	10.6	14.1	8.6	5.6	9.4	8.9			
S.D. Mean		14.0 248.8	17.1 161.3	31.8 225.3	17.4 202.1	11.6 205.6	20.5 217.8	25.9 292.4			

Table A7. Analisis of variance for plant height (cm) for ten maize cultivars and their 45 diallel crosses at seven locations

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^a General combining ability.
*,** Significant at 0.05 and 0.01 probability levels, respectively.

	<u>ultivars</u>	1	2	3	4	5	6	7	8	9_	10
1.	Cacahuazintle		0.0	1.1	-10.5	-7.4	3.4	-5.8	-3.5	-2.8	-2.9
2.	Chalqueño	0.9		-2.0	-7.7	-8.4	-2.0	-1.0	-3.9	-4.4	-4.5
3.	Conico 7	4.0	1.7		-6.7	-8.7	7.5	1.7	-3.6	-0.6	3.9
4.	INIAP 153	-0.8	1.5	6.0		3.7	-4.6	2.3	-0.1	-1.8	-9.6
5.	Morocho Ecua.	3.8	1.9	5.0	5.1		-4.9	-1.8	-4.7	0.7	-14.5
6.	Cacao	6.8	0.4	14.3	2.6	3.5		-0.9	3.8	3.7	3.4
7.	Cabuya	0.9	5.1	11.8	6.2	3.3	2.8		-3.2	-0.7	-7.9
8.	Blanco Urubamba	4.5	3.2	7.2	2.4	-1.0	9.0	-2.0		-0.9	-12.4
9.	Umutu	4.6	2.1	9.9	1.3	5.2	8.1	-0.2	-0.1		-8.2
10.	Morocho Ayacucho	2.6	1.7	6.7	5.1	0.6	12.6	3.8	-0.2	3.9	

Table A8. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for plant height averaged over seven locations for 45 F_1 crosses among ten maize cultivars

<u></u>		Mean squares for each location							
Source	df	Baños	Pampa	Anta	Jangas S.	.Catalina	Chuquipata	<u>Pairumani</u>	
Replication	1	1191.3*	2553.6**	1319.6	692.5	1237.8**	5264.7**	738.4	
Entries	54	1360.5**	425.8**	939.6	595.5**	842.8**	765.9**	2673.7**	
Varieties	9	6414.1**	2050.7**	1256.8	2381.3**	4241.1**	3069.9**	13820.6**	
GCA ^a	9	3799.9**	1434.8**	649.8	1342.3**	2602.6**	2743.4**	10795.9**	
Heterosis	45	349.8*	100.8	876.2	283.4	163.2	305.1	444.4	
Average	1	456.8	87.4	124.7	1700.6**	268.4	30.8	1095.8	
Variety	9	343.5	53.8	1820.5	243.2	235.3*	495.1	565.8	
Specific	35	348.3*	113.6	654.8	195.3	141.6	264.1	394.5	
Error	54	204.8	159.4	1115.8	230.0	109.7	387.4	483.0	
C.V.(%)		9.7	14.0	23.6	13.8	9.6	14.5	13.2	
S.D. Mean		14.3 147.9	12.6 90.1	33.4 141.4	15.2 109.7	10.5 108.9	19.7 135.4	22.0 166.0	

Table A9. Analisis of variance for ear height (cm) for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

	Cultivars	_1	2	3	4	5	6	7	8	9	10
1.	Cacahuazintle		1.6	2.8	-14.9	-12.0	3.6	-13.2	-3.6	-6.9	-6.3
2.	Chalqueño	2.6		-0.8	-17.1	-18.3	1.7	-4.8	0.8	-10.8	-7.6
3.	Conico 7	6.6	3.8		-18.4	-18.1	12.3	-1.8	-5.5	-3.7	0.4
4.	INIAP 153	1.9	-1.5	0.6		3.8	-12.6	0.2	-5.9	-8.8	-21.5
5.	Morocho Ecuador	6.8	-1.5	2.3	5.6		-12.9	-4.0	-13.3	-6.5	-24.1
6.	Cacao	9.9	6.9	23.2	-0.5	0.6		-5.5	7.1	4.1	4.8
7.	Cabuya	-0.1	8.5	16.4	5.0	2.4	3.0		-4.7	-1.6	-17.7
8.	Blanco Urubamba	6.7	10.6	8.0	2.7	-3.8	12.1	-0.5		-5.2	-16.0
9.	Umutu	5.2	0.0	12.3	-2.6	1.6	11.4	0.4	-3.0		-18.9
10.	Morocho Ayacucho	1.4	0.9	5.0	0.1	-1.9	19.7	1.1	-0.3	-1.9	

Table A10. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for ear height averaged over seven locations for 45 F_1 crosses among ten maize cultivars

		Mean squares for each location									
Source	df	Baños	Pampa	Anta	Jangas	S.Catalina	Chuquipata	<u> Pairumani</u>			
Replication	1	71.1	59.9**	0.2	16.3	1605.1**	24.8	19.7			
Entries	54	36.0	6.3	0.4	9.8*	214.5	171.4	21.6*			
Cultivars	9	73.1**	5.1	0.4	16.2*	423.2**	487.5**	27.5			
GCA ^a	9	57.8*	7.8	0.3	9.3	434.4**	271.8*	24.9			
Heterosis	45	28.2	6.5	0.4	8.5	172.8	108.2	20.4			
Average	1	12.4	0.5	0.3	40.8*	1.5	323.2	18.3			
Cultivar	9	8.5	7.1	0.5	10.9	247.5*	128.0	50.8*			
Specific	35	33.7	6.6	0.4	6.9	158.5	96.9	12.6			
Error	54	25.9	5.8	0.5	6.0	147.8	111.3	13.5			
C.V. (%)		154.1	164.0	402.6	103.8	96.6	39.7	101.2			
S.D. Mean		5.2 3.3	2.4 1.5	0.7 0.2	2.5 2.4	12.2 12.7	10.5 26.5	3.7 3.6			

Table All. Analysis of variance for root lodging (%) for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

с	ultivars	1	2	3	4	5	6	7	8	9	10
1.	Cacahuazintle		-4.1	-6.9	34.2	-10.1	-43.1	-35.5	11.4	5.8	-2.2
2.	Chalqueño	12.1		-2.2	-34.5	-50.5	-32.8	-57.9	2.3	-49.9	-38.6
3.	Conico 7	6.9	-0.1		-53.3	-44.4	-48.5	-52.7	-28.7	-6.2	-41.6
4.	INIAP 153	93.0	2.6	-27.6		48.7	12.3	-30.6	-17.9	1.7	49.6
5.	Morocho Ecuador	41.8	-16.9	-7.3	76.2		154.3	-38.0	30.7	-33.6	13.8
6.	Cacao	-3.2	19.5	-8.8	55.2	208.0		-64.8	-6.0	-20.9	-8.6
7.	Cabuya	-30.8	-47.8	-42.3	-4.5	-5.4	-41.4		-22.2	-52.1	3.6
8.	Blanco Urubamba	26.6	32.9	-8.7	8.5	93.1	52.8	-17.3		15.7	32.7
9.	Umutu	23.0	-33.7	22.3	31.9	-3.3	27.2	-47.7	18.9		-31.0
10.	Morocho Ayacucho	o 11.5	-20.0	-25.2	97.2	67.8	48.3	10.5	33.2	-29.3	

Table A12. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for root lodging averaged over seven locations for 45 F₁ crosses among ten maize cultivars
		Mean squares for each location									
<u>Source</u>	df	Baños	Pampa	Anta	Jangas	<u>S.Catalina</u>	Chuquipata	Pairumani			
Replication	1	701.5**	90.0*	19.5	4.7	19.6	121.6	49.1			
Entries	54	79.3**	56.2**	30.4	24.4*	133.5**	115.5**	16.1			
Varieties	9	213.6*	174.9**	31.4	94.1**	481.7**	346.2**	20.2			
GCA ^a	9	169.5**	54.4**	34.6	53.9**	401.7**	114.9**	15.1			
Heterosis	45	52.4*	32.4*	30.2	10.5	63.8*	69.4*	15.3			
Average	1	29.2	357.2**	3.1	95.1*	17.0	221.1*	8.5			
Variety	9	42.6	57.6**	10.2	14.4	33.7	120.4**	8.7			
Specific	35	55.6*	16.6	36.1	7.1	72.9*	51.9	17.2			
Error	54	31.2	18.3	26.5	13.7	36.1	41.1	16.3			
C.V. (%)		71.3	79.8	486.5	89.7	47.8	46.5	115.2			
Mean		7.8	4.3 5.4	5.1 1.1	4.1	12.6	13.8	4. <i>3</i> 3.5			

Table A13. Analisis of variance for stalk lodging (%) for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combining ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

10
-70.6
-55.1
-29.3
-20.1
16.6
-15.5
-7.7
42.8
53.8
j -
L D 4 9 2 3 2 3 5

Table A14. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for stalk lodging (%) averaged over seven locations for 45 F_1 crosses among ten maize cultivars

			1	<u>Mean squa</u>	ares for e	ach locat:	ion	
Source	_df	Baños	Pampa	Anta	Jangas S.	<u>Catalina</u>	<u>Chuquipata</u>	<u>Pairumani</u>
Replication	1	1514.8	3710.8	774.5	433.0	34842.4**	2829.8	37.1
Entries	54	7045.6**	3939.9*'	2688.4	3410.5**	9131.4**	6250.6**	5424.0**
Varieties	9	27446.9**	12599.2**	*5326.2*	6787.9**	25430.8**	17431.1**	16641.9**
GCA ^a	9	16304.1**	8529.1*	*3925.9	6650.8**	13664.4**	15178.2**	12310.9**
Heterosis	45	2965.3**	2208.0	2160.8	2735.0	5871.5*	4014.5	3180.4*
Average	1	39661.8**	17414.2*	*2841.6	46136.9**	23505.6*	20465.3**	32360.6**
Variety	9	2293.6	1928.6	2316.9	2078.6	10113.5**	3299.9	2464.7
Specific	35	2089.5	1845.4	2101.2	1663.8	4276.8	3728.2	2530.7
Error	54	1370.3	1948.5	2258.7	1777.0	3213.6	2593.5	1998.6
C.V.(%)		9.9	25.2	17.8	16.6	25.0	17.7	13.8
S.D. Mean		37.0 370.7	44.1 175.5	47.5 266.8	42.1 254.1	56.7 226.3	50.9 287.5	44.7 323.7

Table A15. Analysis of variance for ear volume (cm³) for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combinig ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

	Cultivar	1	2	3	4	5_	6	77	8	9	10_
1.	Cacahuazintle		-0.2	-3.9	9.5	6.3	12.6	3.3	6.5	-3.0	5.5
2.	Chalqueño	3.7		-2.9	8.5	17.9	5.2	14.1	-4.3	3.1	16.0
3.	Conico 7	1.7	-1.1		2.7	5.6	18.3	11.9	-0.7	-11.1	1.0
4.	INIAP 153	11.7	15.0	10.8		-15.8	-5.4	1.1	-14.9	-2.5	-0.5
5.	Morocho Ecuador	16.7	24.8	9.8	-5.9		23.4	-8.0	-7.0	-11.9	18.9
6.	Cacao	28.0	15.6	27.8	9.5	28.3		-2.0	-1.3	-8.6	29.9
7.	Cabuya	5.4	16.2	16.0	5.3	-1.0	9.4		-15.9	-14.7	-2.9
8.	Blanco Urubamba	17.8	9.5	15.5	-7.6	11.7	22.4	-5.3		2.9	-12.4
9.	Umutu	8.9	19.7	4.9	7.6	7.3	14.8	-2.4	4.6		-17.1
10.	Morocho Ayacucho	18.3	25.5	7.5	13.5	21.7	32.0	6.8	7.3	2.9	

Table A16. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for ear volume averaged over seven locations for 45 F_1 crosses among ten maize cultivars

				Mean	squares	for each 1	location	
_Source	df	Baños	Pampa	Anta	Jangas S	S.Catalina	Chuquipata	Pairumani
Replication	1	0.001	0.010	0.000	0.124*	1.163**	0.035	0.000
Entries	54	0.091**	0.041	0.049**	0.034	0.169**	0.071**	0.088**
Varieties	9	0.477**	0.066	0.165**	0.099**	0.586**	0.276**	0.414**
GCA ^a	9	0.343**	0.078	0.144**	0.086**	0.384**	0.245**	0.274**
Heterosis	45	0.014*	0.037	0.025	0.021	0.085	0.030*	0.024
Average	1	0.123**	0.121	0.021	0.164**	0.475**	0.098*	0.200**
Variety	9	0.009	0.065	0.027	0.026	0.109	0.029	0.018**
Specific	35	0.012	0.027	0.025	0.015	0.068	0.028	0.020
Error	54	0.008	0.040	0.018	0.022	0.059	0.018	0.027
C.V. (%)	F	7.40	25.09	10.36	11.60	22.10	12.09	13.50
S.D. Mean		0.09 1.24	0.19 0.79	0.13 1.29	0.15 1.28	0.24 1.10	13.30 1.10	0.16 1.20

Table A17. Analysis of variance for kernel depth (cm) for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combinig ability. *,** Significant at 0.05 and 0.01 probability levels, respectively.

	Cultivars	1	2	3	4	5	6	7	8	9	10
1.	Cacahuazintle		3.1	4.8	1.5	-4.4	-2.4	-5.1	3.1	3.4	7.3
2.	Chalqueño	6.6		0.6	3.9	2.7	-12.1	-9.8	-1.8	7.4	9.4
3.	Conico 7	7.1	1.8		2.4	-10.5	-5.9	-6.2	-0.5	-5.6	3.4
4.	INIAP 153	2.8	6.1	3.3		-15.0	-11.4	-9.1	-21.7	-11.1	-5.9
5.	Morocho Ecuador	7.5	18.9	2.5	-3.3		4.9	-11.4	-13.1	-19.6	-6.5
6.	Cacao	13.1	4.8	11.1	3.7	8.7		-8.2	-13.9	-6.8	-10.0
7.	Cabuya	3.6	1.6	4.4	5.5	-8.5	-2.0		-20.5	-23.2	-9.6
8.	Blanco Urubamba	14.1	5.4	8.0	-14.3	6.8	8.6	-4.8		-8.6	-5.5
9.	Umutu	10.6	11.2	-1.0	-6.1	-4.2	2.1	-10.8	-5.2		-8.8
10.	Morocho Ayacucho	7.7	12.6	5.2	-5.1	5.5	4.7	-0.9	4.1	-2.8	

Table A18. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for kernel depth (cm) averaged over seven locations for 45 F₁ crosses among ten maize cultivars

		Mean squares for each location									
Source	df	Baños	Pampa	Anta	Jangas	<u>S.Catalina</u>	Chuquipata	Pairumani			
Replication	1	3.6	16.0	0.4	14.5	75.3**	0.0	11.1			
Entries	54	13.1**	15.5**	15.4	8.8	13.7**	21.8**	17.3**			
Varieties	9	55.1**	48.5**	64.0**	21.2**	57.5**	54.8**	55.8**			
GCA ^a	9	36.7**	46.6**	37.7**	15.4**	41.0**	48.2**	50.9**			
Heterosis	45	4.7**	8.9*	5.5	6.3	4.9	15.2*	9.6**			
Average	1	81.2**	0.5	64.4**	99.1**	6.4	16.5	54.0**			
Variety	9	3.3	13.0*	4.4	5.3	5.8	15.2	11.6**			
Specific	35	2.9	8.1	4.1	3.9	4.6	15.1*	7.8**			
Error	54	2.3	5.0	4.2	6.6	4.4	8.2	3.0			
C.V. (%)		5.7	11.8	8.1	11.2	9.7	11.3	6.4			
S.D. Mean		1.5 26.7	2.2 19.0	2.0 25.3	2.6 23.0	2.1 21.7	2.9 25.3	1.7 26.9			

Table A19. Analysis of variance for number of kernels per row for ten maize cultivars and their 45 diallel crosses at seven locations

^a General combining ability.
*,** Significant at 0.05 and 0.01 probability levels, respectively.

Cultivars	1	2	3	4	5	6	7	8	9	10
1. Cacahuazintle		-2.1	-4.1	5.9	7.1	11.8	12.1	0.9	6.5	-9.6
2. Chalqueño	5.2		-2.4	3.5	6.9	-0.5	2.4	-7.5	-3.2	-9.9
3. Conico 7	2.4	-1.7		-3.5	-1.6	3.2	2.4	-8.1	-5.1	-13.8
4. INIAP 153	6.7	12.0	3.8		-0.6	2.2	1.2	0.6	4.4	0.0
5. Morocho Ecuador	11.6	19.3	9.1	2.8		9.2	8.1	0.0	5.9	-2.2
6. Cacao	13.3	8.3	11.7	2.8	12.3		0.3	-6.4	2.5	7.6
7. Cabuya	12.2	10.2	9.5	1.9	12.4	1.6		-6.2	5.9	-1.2
8. Blanco Urubamba	3.0	1.3	0.0	-0.6	2.5	-5.8	-4.4		-4.7	-6.1
9. Umutu	7.0	4.5	1.7	4.7	9.9	3.5	6.9	-3.2		-5.0
10. Morocho Ayacucho	2.8	9.0	3.7	13.0	12.2	20.9	12.2	4.9	7.6	

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Table A20. Values of high-parent heterosis (%) (above diagonal) and mid-parent heterosis (%) (below diagonal) for kernel number per row averaged over seven locations for 45 F_1 crosses among ten maize cultivars